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ROBOTICS AND AUTOMATION IN THE MINERAL INDUSTRY

Seminar Proceedings
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MICROMEDIA

PREFACE

This publication is the full account of a seminar held in the fall of 1983 on the relatively new subject of Robotics and the Mining industry.

The format of this seminar has been somewhat of a departure from the standard workshop normally held by CANMET, but is fully in keeping with our mission of complementing industry's efforts to improve productivity through the injection of new technology. Robotics has made some remarkable breakthroughs in the manufacturing sector. While CANMET does not intend to get involved in robotics development per se, it is keenly interested in seeing that the Canadian mineral industry does not lose any opportunity to apply robotics technology to its special problems. In keeping with such a policy, CANMET has contracted selected development projects that were discussed in the seminar. I welcome the publication of these proceedings as yet another effort to bring government and industry scientists together. I only wish to thank the organizers and editors of these proceedings, Drs. Paul Mainwaring and André Potworowski, for their efforts and creativity in seeing this project to completion.

W.G. Jeffery
Director-General
CANMET

PRÉFACE

Le présent document est un compte rendu intégral du colloque qui a eu lieu à l'automne 1983 et qui avait pour objet l'utilisation de la robotique dans l'industrie minière.

La programmation de ce colloque était en quelque sorte différente de la programmation habituelle des ateliers de travail tenus par CANMET mais exprimait notre volonté d'appuyer les efforts de l'industrie quant à l'augmentation de la productivité par le biais de la nouvelle technologie. La robotique a fait une percée remarquable dans le secteur de la fabrication. Bien que CANMET ne désire pas collaborer directement au développement de la robotique, il est vivement intéressé à ce que l'industrie canadienne des mines puisse utiliser la robotique pour solutionner les problèmes qui lui sont propres. Par conséquent CANMET a entrepris certains projets de développement qui ont fait l'objet de discussions lors du colloque. La publication du compte rendu de ces discussions m'apporte une grande satisfaction, car elle symbolise les efforts qui sont faits en vue de rapprocher davantage les scientifiques oeuvrant au gouvernement et dans l'industrie. Je voudrais surtout remercier Messieurs Paul Mainwaring et André Potworowski de l'effort et de l'imagination dont ils ont fait preuve pour la réalisation de ce project.

W.G. Jeffery
Director-General
CANMET

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INTRODUCTION

1. INTRODUCTION

1.1 Why a seminar on robotics?

The idea of holding a seminar on robotics arose from a visit to the annual robotics show held in Chicago in April 1983. That year, the manufacturing and sales of commercial robots in North America represented a $200 million industry. It was thought then that CANMET scientists could benefit from more exposure to this fast-advancing, high-technology industry. The original idea was to limit the exposure to an in-house seminar in which the state of the art would be reviewed. However, as it became apparent that the mining and processing industry was keenly interested in improving productivity with these innovative technologies, the idea expanded. To use Dr. Whitman's metaphor, the seminar grew like Jack's beanstalk. Finally, the decision was taken to hold a national seminar in Ottawa.

CANMET has been active in the field of automation and robotics. A number of contracts have been let in this area and these are reviewed by David Gladwin in his paper. It is recognized that CANMET has a role to play in the mining-machinery sector; however, that role is not to design machinery. This activity is better left to the private sector.

1.2 The Ottawa Seminar

It should be pointed out that the seminar was never intended to cover all the technical, economic, and social issues facing the application of robotics in the mineral industry. It was organized, rather, to stimulate awareness and discussion among CANMET scientists and industry on this fast rising technology. Some even think that robotics and automation will have as profound an impact on our economy as the industrial revolution in the last century. For it is possible that the application of these systems could well provide the next substantial step in productivity

improvement. Judging by the highly intense discussion in the panel session and over lunch afterwards, the editors feel confident that their objective was fully met.

What follows is an overview of the main points raised at this seminar, followed by a slightly edited transcript of all the papers and the panel discussion.

2. SEMINAR OVERVIEW

2.1 Lesssons from the Manufacturing Sector

V. Valeri from Westinghouse/Unimation in Pittsburgh reviewed the status of robotics in the manufacturing area and the current approach to implementation. His expectation was that the manufacturing sector's experience of successes and pitfalls should help the mineral industry in its efforts to automate plants for the future. Valeri's specific objective is to apply the technology that is now available.

> "Falling in the category of current technology comes industrial robotics defined as the integration of industrial robots in the manufacturing environment."

A number of definitions of robots and automation currently exist. The most rigorous is that proposed by the Robotics Institute of America:

> "a robot is a programmable, multi-functional manipulator designed to move material, parts, tools or specialized devices through various programmable motions for the performance of a variety of tasks."

Referring to the Robotics Institute definition, Valeri stressed that the most important aspect of a robot is that

> "... it is reprogrammable, meaning that it is controlled by a computer and it can be instructed to perform a different sequence of movements through the use of a different program or a different sensory feedback."

To Valeri, a robot is more than the robot itself. It is only part of what is referred to as a manufacturing cell which involves four basic components: the manipulator or the robot arm and its base; the computer which is technically

considered part of the robot; and the peripheral or auxiliary equipment, for example, welding positioning tables; and people:

> "...people, because people are essential for the development of a robotic system and it is people who are responsible for its effectiveness. People (are important) to design the system and monitor its operation, to teach the robot how to operate through the reach of a remote control manipulator, and to program the computer which controls the robot."

In robotic applications, Valeri emphasized the robotic system as a whole. The system includes the manufacturing process or operation which utilizes the industrial robot.

> "Although it is possible to buy a robot off the shelf it is not possible to buy a solution to your problem or any other manufacturing problem, off the shelf. Probably the most important element in implementing a robot is the application technology. It is a misconception for people to think that robots have "do anything" capabilities; instead they are limited to performing only certain operations based on their initial design consideration and therefore it is the job of the applications engineer to find the right places for the right kind of robots and to make them work."

Mr. Valeri then reviewed current applications of robotics in the manufacturing sector. The largest application of robots at this time is in resistance welding.

> "Practically all of the spot welding operations performed on automobile bodies are now being done by robots. Not only do they reduce labour costs, but robots are also

> capable of applying the weld more precisely when and where it is needed. This naturally improves the quality of the product as well as reduces waste. Furthermore robots can hang upside down from the ceiling, can be mounted on the wall to help save space in the factory and to get the best utilization of both the floor space and the equipment."

Other major applications include material handling, paint spraying, and dipping applications in foundry and die-casting. The benefits of a robotic system include improvements in productivity, quality, efficiencies, people's productivity, and reduction in long-term costs; all leading ultimately to increased profitability.

The next level of innovation will be the automation of an entire factory, which involves moving to a new level of control. At the first level, control is applied to a specific task in a work cell. At the next level the various tasks are integrated into a single control, which becomes an island of information,

> "...i.e., what we normally call a work cell in itself that has been expanded over the years to a numerical or a programmable control type of system called a DNC (direct numerical controller) system where we have one controller. This means that we have one computer that sends out to the computers of those various machines the programs that each of those machines needs to implement in order to process the material through it."

The next step is to take those direct numerical control systems and connect them to a business computer, which has the information of what product is required to be manufactured on a particular day and adjusts the programs and the material flow in order to make the required product or, depending on what labour force is available, decides how those programs have to be adjusted. Such an automated

factory would have the flexibility that allows the business computer to pass on to the factory the business and manufacturing requirements for that particular day and would control the equipment operation making all the necessary adjustments to meet both the costs and the business demands of the firm.

2.2. Applications in the Minerals Industry

Valeri's view of robotics as applied to the manufacturing sector was compared with the application of robotics technology to the mining and minerals sector. Based on a number of studies developed for CANMET, David Gladwin was able to identify

> "...a series of stages in moving towards application of robotics technology, and these start at the manual process control stage which is where we have individual labour action perhaps extended by basic machines."

This is demonstrated in various mining operations such as drilling, which evolves through initial stages of mechanization, the use of basic mechanical equipment, and progressively becomes more complex and sophisticated and extends the capacity of an individual operator. However, the operator must be on the machine to control it. The next stage is to take the operator off the machine.

> "In mining we now have examples of that in the remote controlled scooptrams, some raise boring; and in processing plants, we have central control."

This might enable one operator to overlook more than one machine. Again there is a potential for increased productivity. But this increase still relies upon the skills of one operator or requires the operator to observe and control all the machine functions.

The next step toward robotics includes monitoring systems, control systems, and the capability to automatically and routinely sense the operating parameters in the work place. This will gradually move from simply being able to sense these parameters to actually implementing responses to these parameters.

> "This takes you into automation, the automatic control of operations, which combines the monitoring capability with the machine functioning capability we have with remote control. Ultimately, control technology will lead us through to robotics, or the applications of logic controlled equipment to do our mining."

There are many levels of application of robotics technology throughout the inddustry, ranging from automatic-controlled operations to logic-controlled equipment.

Some parts of the industry are still heavily dependent on manual process control operation.

> "At this point in time there is very little application of what we might call robots in mining, the top level of automation. I think that this is a long way away, and that it is a long-term R&D venture."

Henk Van Deudekom identified three areas in which there could be an opportunity for increased automation in mining: improvement in equipment availability; the extension of equipment life; and the enhancement of productivity.

Equipment availability can be improved through selective monitoring of operating parameters of machine functions which will enable prediction of maintenance needs for specific components and detection of incipient failures. This will require the introduction of sensors, on-board microprocessors, and peripheral equipment external to the machine to periodically collect, process and analyze the

data generated. Adoption of such technologies will bring an effective reduction in maintenance and spare part costs and improvement in machinery availability.

Equipment life can be extended by adding controls to the sensors and micro-processors to allow them to override the operator's commands as required to ensure that the equipment is functioning within its designed limits. This would force the operator to work within the machinery's capacity and avoid practices that could damage the equipment.

Productivity improvement will be achieved through a much closer examination of how equipment is used and how manpower reductions can be effected.

Mr. Van Deudekom went on to describe how a small company, like his, sees the issue of robotics in the mining and mineral processing industry, and some of the issues in identifying costs and benefits.

Neil Roberts of CANMET's Physical Metallurgy Research Laboratory reviewed the areas in the metallurgical industries where robots can play a useful role. These included pick-and-place robots working in casting shops, steel mill automation (where the Japanese are particularly advanced), welding and spot welding, and non-destructive testing. One such device for non-destructive testing developed in CANMET, is an X-ray diffractometer that is portable and can be taken into the field to measure surface stresses in metal structures.

> "One could envisage, if you really wanted to do X-ray mapping of the surface of a complex piece of metal, mounting this device on the end of a robot. This would be a very useful device in this configuration."

2.3 The Challenges of Underground Hard Rock Mining

J. Pathak presented an overview of some issues which face the application of high technology and robotics in underground hard rock mining. He contrasted the ease of automation of underground coal mining with the difficulty of the underground hard rock mining situation. In the case of vein-type deposits, he stated that

> "...it is difficult to trace the outline of the orebody more than a few metres in advance. In one of the uranium mines we visited in Saskatchewan, the variation in grade of the orebody was so drastic that every scoop had to be sensed before deciding whether it would go to the waste-rock pile or to the mill."

This great unpredictability makes the application of any automatic system very difficult.

Dr. Pathak reviewed some of the issues in adopting new technologies and stressed the extreme rigour of the underground hard-rock mining environment. Repeated equipment and materials failure make mining engineers and mine operators pessimistic about unproven technology. Nonetheless, he acknowledged that it will be difficult to keep underground hard-rock mining isolated

> "...from the assault of high technology. Signs of its entry are already appearing and it is the right time for Canadians to jump into it before we realize that it is too late."

He identified a number of technological advances that could be implemented in the foreseeable future. The first is the move towards electrification of mines.

> "Electrification is particularly advantageous in cold countries like Canada where we will save by not moving the additional air volume required for diesel horsepower as well as by not having to heat that additional volume."

The use of electrical power is more energy efficient and offers far lower maintenance costs.

Another high-technology application is the down-the-hole (DTH) drilling technique applied to the Vertical Crater Retreat mining method developed in Canada.

> "The DTH drill needs the development of instrumentation for proper alignment, as well as on-line information of the orientation and deviation of the drillhole."

This instrumentation would essentially control the direction of drilling and stop the drill if it moves off course. It requires digital recorders, compatible with computer-aided design systems with three-dimensional graphics. Other software systems could provide reports to the blasting foreman which would contain all information needed to carry on blasting and drilling.

> "By using microprocessors, various drilling parameters could thus be sensed, and drill automation could be optimized, giving maximum attainable penetration with minimum wear on the drill bits."

Dr. Pathak then described a remotely controlled out-of-sight system for mining, which conceivably could be applied to high uranium content orebodies. This would consist of long drillhole technology, associated with underground mine development carried out without exposure to high radiation. Remotely controlled electric scooptrams and driverless trucks, controlled remotely by trolley wire and automated conveyors, would complete the system. A series of remotely controlled television cameras and flood lights

would assist in controlling and operating these units from a radiation-proof control room. One weak link in the system is the lack of portable crushers of suitable size needed to rapidly remove broken ore or waste from the excavation operations.

Finally, new technology that will have a definite impact on mine automation is the increasingly sophisticated management information system. While not strictly a part of robotics, management information systems are an essential step in the continuous evolution towards full automation. J. Pathak underlined the importance of underground communication in hard-rock mines and its present inadequacy and described the real advantages to be obtained from a **Mine Status Indicator (MSI).** The MSI would eliminate the time lost by shift bosses in collecting daily operations parameters in a mine. Such data is essential for the day-to-day deployment of the operational resources.

In the panel discussion, Vic Jutronich (Denison Mines) pointed out that this kind of information is important to keep a plant operating properly. However,

> "...a lot of the information becomes available in two, three, or four weeks after the time beyond which it is too late to correct a problem. If such a real-time monitoring system were installed to provide status indicators at the end of each shift, action could be taken right away."

The potential for productivity improvement using such a system would be substantial.

Other management information systems outlined by Dr. Pathak included mine environmental monitors with sensors to detect methane, carbon monoxide, temperature and air velocity. These sensors are well developed and proven, while other sensors are being evaluated. Other monitoring

systems are directed to ventilation and can provide substantial savings in reducing the requirements for intake error and heating costs.

Monitoring or sensing of variables is the first step before attempting to build automatic control systems for application of the monitoring information. According to David Gladwin,

> "We can monitor today, the electrical draw at various points in the mine. We can monitor compressed air draws at various points, the pump activities and other parameters. Just as easily as we can monitor those, we should be able to control them, and I think there are examples already of what we might call in robotics, rudimentary systems."

Such systems that monitor, interact, check against parameters, and control are likely to have a much higher degree of acceptance at the operation level than a mere monitoring system. The short-term challenge will be the development of the required sensors and the only thing that might prevent the implementation of such systems is the very high cost. CONSPEC, one company currently contributing in this area, is working on a computer integrated mining system, which integrates all the primarily underground mining activities into a total system.

2.4 Mineral Processing Applications

The only current attempt to apply robotics technology in a mineral processing plant described at this seminar, was that of INCO's "bar-and-hammer" tuyere puncher for copper converters. This was described in some detail by Don Saville. INCO chose the bar-and-hammer project for robot type R&D because hammering is the most common physical task required in their plants. The copper converter was chosen because this task is normally carried out in unpleasant and somewhat hazardous conditions: heat, dust, gases, very high noise level, all requiring special protection for the workers. Don Saville explained,

> "Despite that, when we finally arrived at this CANMET contract and made this known to the workers who work in this specific area, they were not happy at all. I went to speak to these people and said, 'We're going to try and develop a device that will replace you in this terrible job.' They suddenly decided this was a very good job and that it wasn't as bad as they used to think the week before or in the last three union contracts that had this item on it."

This reference to the potential impact of displacing workers is considered important, although it was not addressed at the seminar.

The importance of analyzing processes and developing correct sensors was established by Daniel Laguitton, a CANMET research scientist,

> "Before we move any further, we have to analyze the process and decide what sensors are required. More work on process analysis and process theory is required in order to develop adequate control strategies."

This means we must identify the most important variables to be measured and the best locations in a plant to measure them - which will require much time - then we must develop the sensors to measure the important parameters and **only then** will we be able to address the issue of developing the machines and process equipment. Finally, we will be able to couple sensors with what could be called a robot or automatic control system where the process theory will be used to optimize and supervise the process.

Louis Cabri (CANMET) confirmed this, stating that there are still many processes in the metallurgical and mining industries which we do not yet fundamentally understand.

> "That is why it is hard to automate and find robotics applications and I think this should be recognized. We should really consider that some aspects of the mineral industries have not had the same sort of fundamental research as other hard sciences have had."

In reply to Louis Cabri, Henk Van Deudekom stated,

> "If the metallurgical processes are not adequately characterized at this moment to allow us to even specify what kind of sensors we need and to control them, then that is an indication as to what the priorities should be as far as development expenditures are made."

William Petruk (CANMET) described one of the more innovative mineralogical sensors. This sensor incorporates today's technology and could have a profound impact on whole mineral processing plants in the near future. By using a scanning electron microscope and an X-ray detector, selected samples can be characterized with an image analyser, grain by grain, to determine the mineralogical composition of the product of a process. If this were done on-stream at selected points in a plant and were correlated with on-stream X-ray fluorescence analysis, it would provide invaluable information for the computer control system of a mill. This information could be fed into the plant operation and would offer the potential to select more accurately, the material that would be accepted into a particular concentrate stream. The technology is already in place in other countries, (e.g., Australia) where it has been developed for automatically selecting, sizing, and polishing mineral samples for this kind of scanning electron microscope analysis. Such an automated mineralogy analysis has the real potential of increasing metal recovery and, therefore, the profitability of companies.

Don Saville (INCO) described the automatic technology available today.

> "We have automatic sampling, automatic assaying, automatic collection of that data, and the translation of it, but so what? We already have too much data, in some areas, that we cannot fully use at the present time."

This sentiment was substantiated by Daniel Laguitton (CANMET) who drew attention to the necessity of a fully integrated systems approach in which data gathered in all processes in a plant would be transmitted to a plant optimization computer. This computer, through data analysis would be able to answer questions such as: is the mill making the best use of the energy provided to it in a particular area - such as a grinding circuit? how is process optimization to be achieved? is it achieved? Daniel Laguitton restated:

> "...we still need to go back to the basics - understand the process fully, redesign or adjust the sensors, then automate the plant and that will be the basis of a more efficient and economic way of operation."

2.5 Sensors: The Weak Link

> "We have to decide what we need to measure and then find something to measure it."

Although the topics of monitoring and control systems, management information systems, process monitoring and control, and sensors are all related, the subject of sensors clearly came out in the discussion as one deserving particular attention, especially from CANMET's research and development's perspective.

It was Dr. Art Hunter of NRC who pointed out that William Petruk's automatic image analysis system and the X-ray stress diffractometer were potentially very useful sensors and had very clear applications to automation and robotics.

> "One is looking at the development of sensors which will function in an environment which is particularly nasty in that it is dirty and dusty - unfriendly is a term that was used as well - whether it be underground or on the surface. There is a great deal to be done to go from the technology that was developed for the Canadarm to that which is used in this environment that is going to require extremely rugged designs."

John Wilson of the Ontario Centre for Research Machinery was optimistic and agreed.

> "We have the technology, we can monitor systems underground, we can monitor the height of the muck in the ore passage, we can monitor ventilation conditions, and we can raise and lower ventilation doors. We have the technology, let's put it to work."

However, at the metallurgical end of mining, Don Saville was less enthusiastic.

> "The pyrometallurgical business is still 50% black art, and it is done by a person who in some manner looks at his particular metal and gives it some tests that may or may not exist in fact, and decides if it is a good one or a bad one. We have very little control over our roasting process. We don't really know what happens, all we know is that it comes out all right. In order to take people away from those work faces and eliminate those particular tasks in the industry, we have to

> find ways to measure whatever it is. **We have to find what it is that we need to measure and then find something to measure it."**

Neil Roberts also supported this view that sensor development is crucial and described the difficulty of performing the simple measurement of temperature on a continuous basis in a molten bath of metal.

> "You can put in numerous thermocouples and have them chewed up by the mill, time and time again, or you can use pyrometry which doesn't really seem to be very accurate. At present there doesn't really seem to be a very good method, inexpensive and reliable for measuring temperature."

2.6 The Social Economic Imperative: The Challenges of Implementing New Technology

Several speakers made passing reference to this dimension. Because of its importance in the ultimate adoption of new technology, it was thought that this topic deserved a separate section, albeit very brief. V. Valeri's imperatives for automation and robotics were based on the manufacturings sector's perception of productivity and unit cost. V. Jutronich of Denison is equally concerned about his company's internationally competitive position and is concerned about the rapid progress made by such countries as Korea, China and, in the longer run, India and African countries, in adopting new mining technology before we do.

For D. Saville the major difference between manufacturing and mining is that the increased productivity opportunities gained in manufacturing, for example by automated robots, are used to increase manufacturing capabilities.

> "We don't have that opportunity in our particular mining business. I suppose if you had a gold mine this would not be true, but we don't have a gold mine, although gold is one of our by-products. We cannot make more nickel and so we don't have the opportunity to lower our unit cost by making more, because we cannot sell it - even though we are the largest nickel company in the world. The market is not there at this time and I don't see that it will be there for some time to come."

In other words, in a fixed market for bulk commodities such as metals, **productivity improvements have to come from reducing the cost of production.**

J. Pathak identifies one problem in implementing advanced technologies. It is necessary in some cases to demonstrate new techniques to profit-oriented operators in an environment that does not involve their total responsibility from a financial point of view but still makes them participants in these endeavours. This can be achieved through a research establishment, like a research mine, where different mining methods can be tried out without any real cost to producers. Finally, Mr. Valeri stresses the importance of qualified people to make automated systems work properly. But it was D. Saville who flagged the risk of the possible negative impact of displacing workers through the implementation of automated systems.

2.7 CANMET's Role

Both Dr. Jeffery and Dr. Whitham outlined CANMET's concerns in the area of mining and mineral equipment and new technology. Although CANMET will not design such equipment because it does not have the mandate or the capability, its knowledge and experience with the mining industry puts it in a unique position to help implement new technologies.

David Gladwin reviewed CANMET's most recent activities in this area. These included an on-going assessment of industry needs and potential for robotics applications. One effort consists of surveying operators regarding high technology and how it may affect their operations. Another effort consists of assessing the current status of mine equipment maintenance systems.

A further thrust includes a number of efforts related to specific equipment capabilities in selected areas, largely in response to industry proposals. These include the building of a prototype mini-hydraulic scaler/rock bolter. Another is the bar-and-hammer prototype robot device currently being developed by INCO. In addition, CANMET is involved, less directly, with the tunnel boring machine built by Lovatt Engineering, and related to it is the development of an erector-transporter by Beaver Equipment. Both apply to coal mining. Another project is related to the development of a prototype down-the-hole drill control system and logger.

A fourth main thrust of CANMET's current program is the development of greater mine design capability. One project consists of developing software to assist planners in improving the use of explosives in underground mines.

And the fifth main thrust is directed at developing operational control systems, one of which is directed at monitoring the mine environment and another is directed at the simulation of the processing of ore and coal (SPOC).

It was stressed that the future direction of this program is flexible and depends largely on input received from industry. Dr. Jeffery concluded,

> "...in terms of the CANMET mission and the allocation of scarce resources to this field, we seek input, we seek guidance from the industry. We serve the mining, the metallurgical, the mineral processing and indeed the energy industries, and we may

proceed with other seminars of this nature, perhaps more detailed, on some of the work we are trying to do. We are looking to industry proposals flowing in - we don't say we are going to be able to accomodate all of them -but it is that participation between CANMET and industry which will move technology forward."

3. OPENING REMARKS

Dr. Kenneth Whitham, Assistant Deputy Minister,
Research and Technology Sector,
Department of Energy, Mines and Resources

It is with a great deal of pleasure that I join you this morning to open this seminar on Robotics and Remote Manipulators in the Mining and Mineral Processing Industry. I would like to welcome all of you who have come to participate, especially those from industry, and I would like to express our thanks to those who are presenting their thoughts and views in the prepared papers this morning.

Dr. Jeffery, the Director General of CANMET, who you will hear from at the end of this morning, tells me that I should be quite frank and say that this seminar just grew and grew - rather like the beanstalk planted by Jack. It began as simply one of a series of informal discussion groups, that we encourage among professional staff within the CANMET laboratories. The objective was to review this new and exciting field of Robotics with the idea of heightening the awareness of our scientists so that they would be on the lookout for potential applications and novel ideas. As you will learn later this morning when David Gladwin speaks, CANMET has not been inactive in this field. The seminar was, however, mentioned to a number of interested people with whom we have contacts and subsequently this interest became so strong that we have yielded quite willingly and the seminar has been expanded from the usual small conference room with a period of perhaps one hour to Camsell Hall and indeed the entire morning.

Now that we have reached this stage, what do we hope to get out of it? Well, one important function is still to provide for an exchange of views and a heightened awareness of the stage to which robots have developed.

With the presence of those in the private sector who are hoping to see this as a profitable and worthwhile industry, I would hope that CANMET management can receive ideas on where they

could be of assistance or, conversely, where they should avoid becoming involved. CANMET does have an overall approach or program regarding this field of endeavour and you will hear more about this, as I mentioned earlier, in the presentation by David Gladwin from Research Program Office, during the course of this morning. I think he will show you how some excellent early review reports done under contract by Robertson Nickerson and Montreal Engineering in the field of machinery, which have been much in demand both in Canada and abroad, have led to a series of contracts on some detailed projects.

However, without getting into such details, let me say that the federal interest in mining machinery and equipment stems from the late 1970's and has been maintained by a number of ministers of my department.

As the Mineral Policy Sector of the Department and the Machinery Branch of the Department of Industry, Trade and Commerce went through a series of reviews of the dynamics of the mine machinery business, the economists and trade analysts and commerce officers in these organizations looked to CANMET for the necessary technical expertise within the federal government. And they did this because CANMET is the major mining and minerals technology arm of the federal government. However, while CANMET does conduct R & D in mining and mineral processing, its staff could generally be described as a staff of scientists and research engineers, rather than industrial design engineers or machinery specialists which, perhaps, are required for robotics development.

It was decided that CANMET should not develop a capability in machinery design, which we regard as a field more suited to the private sector. However, we must respond to ministerial policy directives and, of course, we must be responsive to government technology policies. And CANMET has considerable interest and expertise in mining and in mineral processing, both of which appear capable of benefiting from the specific application of new technologies. So it is this interest in the applications of robotics and other new technologies, and our

mandate to support the enhancement of both productivity and safety in the mining, minerals and metals industries that have led us to the current approach and to the series of contracts that David Gladwin will outline to you.

We hope that your suggestions will help us to guide this contract program in the future.

Now, I think it is quite clear that the federal government both wishes and intends to invest in technology for Canada. The dilemma, however, is always what proportion of scarce dollars and in what areas. If robotics, like biotechnology, or computers, or as it is sometimes called, information technology, has an exciting future, then we must encourage some Canadian roots now while there is still room for new plants. We expect that these new plants would have to be nurtured by venture capital, the mining industry, and possibly the federal government in these early stages, to encourage a healthy relationship between the producer and the consumer.

Canada has one of the world's great mining industries, and there is no reason why we should not be in the forefront of new technologies relevant to these industries. Indeed, if there are productivity advantages, as well as health and safety advantages, we have got to be in the forefront.

So, I would like to close by saying that we are fully aware, and we indeed welcome the involvement of other governments to encourage these industrial ventures and new technologies. We are extremely pleased to have with us representatives of the Ontario Centre for Resource Machinery and the Ontario Robotics Centre. Again I will say that CANMET is not in the business that they are in, and yet we are anxious to assist in any way that we can with, for example, support through our knowledge of problems and needs in technologies related to such aspects as health, safety and the environment.

Fundamentally, we are all involved, in the short and long term, in improving the productivity and, therefore, the competitiveness of the Canadian mining and mineral processing industry. It is clear that in many ways robotics and remote

control will do this. Perhaps it will do it in a revolutionary manner, perhaps more in an evolutionary manner. But in any case we will all be better off if we understand fully the implications and the impact.

I hope that this meeting this morning will be one useful step towards that aim. I hope you all have a very successful meeting. I think that this is an area of great concern and interest to the federal government.

SEMINAR SESSIONS

4. OVERVIEW OF ROBOTICS IN THE MANUFACTURING SECTOR

V. Valeri,
Westinghouse/Unimation,
Pittsburgh, U.S.A.

When Dr. Mainwaring originally asked me here, we recognized my experience is in manufacturing and not directly related to your business in mining.

But Dr. Mainwaring's objective was for me to discuss what is being done in the manufacturing area and how we are going about it, and about the successes and pitfalls. And from that experience I hope to help you in your efforts to automate your plants for the future.

Westinghouse, along with many other large corporations, is dedicated to the development and application of current technology in industry. What you have been looking at (in the film) is some of the research and some of the 'Star Wars' kind of activity, some of the development work activity that is going on. My specific objective in industry is to apply the technology that is now available. Falling under the category of current technology comes the integration of industrial robots in the manufacturing environment. More simply, robotics, as referred to here, is the use of robots in industry.

Of course, robots were not developed overnight. It started with the industrial revolution when it was discovered that methods and machines could be used to improve output. One concept that emerged during that era was the assembly line process - a mass production technique that is still being used today. Essentially, it enabled a factory worker to be more productive, which is the key to improved overall productivity.

As you know, the automobile is basically assembled by hand. Two men insert the seat as the final assembly operation. This technique offered many advantages: it saved time, it was easier, it lowered the cost of production, and as a result it created jobs that made the automobile affordable to the average

consumer. And as time went on, of course, technology made possible much more than the automobile. It was this dedication to the development of technology which made the United States a leader in industrial markets.

But something happened. Americans became too confident and they failed to recognize the impact of foreign competition. Instead of updating their manufacturing methods and utilizing the technology which was available they relied on the image of the United States as a leader to maintain their position while the competition was hard at work improving productivity, quality, and providing goods at a lower cost. Basically, the United States lags behind its competitors in terms of productivity growth. Productivity, which refers to getting the most possible out of the resources available, is the key.

For example, the United States possesses a strong technological base, but it was the Japanese who put into practice the concept of the importance of people in applying technology. Using the theory of participative management, in which employees are encouraged to make suggestions and to become more involved in the decision-making process of upper management, the Japanese have managed to gain the support of their total work force in utilizing robotics technology. It is interesting to note here that the first robot used in Japan was manufactured in the United States by Unimation. Essentially, the United States must, and is seeking to, utilize its robotics technology through the support of its people.

But of course this requires change and the change represents a threat to many people. It is easier to cling to the past and to the traditional methods that we all know than to accept and adapt to change. In other words, the limiting factor in technological change is the ability to introduce and manage that change. Once this problem is addressed, the application of current technology becomes possible. Very simply the widespread application of new technology - robotics technology, for example - depends on an increase in awareness and a new, people-oriented attitude.

Using this approach, the United States will be better prepared to address the need for improved productivity and improved product quality opportunities for the eighties, which will help to establish leadership in the world market!

A question most often asked is this: what about the labour force?

How will employment be affected by robotics technology? Well, to make the answer as simple as possible, consider the advent of mass production which I mentioned earlier. People were displaced at first, but the end result was that more jobs were created because a larger market was developed and a general improvement in living standards resulted.

Industry is in a transition period. Old jobs are being reduced or eliminated, and new jobs are only starting to be created. It has been a gradual process so far; however, I believe we are on the verge of a technological revolution. The importance of retraining people has been recognized and, as with any type of new technology, people need to understand these changes, of which robotics is only one part.

This brings us to a question of just what exactly do we mean when we say "industrial robot"? Well, it is certainly not the R2-D2 or the Mechanical Man, and it is not capable of reasoning by itself, like you just heard in the movie, and it must receive precise instructions on how to operate. An industrial robot is by definition a reprogrammable, multi-functional manipulator. But, most importantly, it is reprogrammable, meaning that it is controlled by a computer and it can be instructed to perform a different sequence of movements through the use of a different program or a different sensory feedback.

An impressive sight (Figure 1) is this entire floor of Japanese robots which are ready for shipment; an indication that the manufacture of robots has also come of age in this world. In fact there are many different types of robots available, in many shapes and sizes and designed to perform a number of tasks. I'll quickly go through some.

Figure 2 shows a welding robot. It can be used for a multitude of other jobs, but because it is equipped with the proper welding equipment, we are using it exclusively in the welding area... some robots are used to handle parts and do a material handling type of operation. Some of them are more sophisticated and some of them less.

Another robot can pick up assorted candies and pack a candy assortment in the boxes that you buy for your wives.

Other types of robot include the one shown in Figure 3 - a three arm robot which is used for small, light assembly operations, especially in the electrical components, electrical relays and circuit breakers.

And another example is the large robot which is used for welding, and which can weld much larger structures because of its size. These can be as long as six metres but this robot was designed specifically for the welding of earth-moving equipment, equipment such as you are familiar with in the mining industry.

On the other hand here is another robot (Figure 4) which can be classified somewhat as a machine tool, i.e., industrial machines used in manufacturing operations which can perform more than one operation depending on the end effector which is used. In this case, for example, the end effector is a welding torch, which is following the path that it was programmed to do. But this robot is modular in size and can be expanded in all directions, and it also has been used for such operations as plasma torch cutting, oxygen lance cutting, water jet cutting, laser cutting, and many other processes. As you develop the processes required for your particular industry, then that marriage with the robot is what is called the applications engineering end of the business, which allows your processes and your product to be adapted to the robotic and automation equipment available.

It's important to understand there is more to a robot than the robot itself. A robot is only part of what we call a manufacturing cell which involves four basic components: the manipulator, or the robot arm and its base; the computer, which

is technically considered part of the robot; the peripheral or auxiliary equipment - in this particular case we are talking about two weld-positioning tables; and the people.

People are essential for the development of a robotic system because it is people who are responsible for its effectiveness: people to design the system and monitor its operation, people to teach the robot how to operate through the reach of a remote control manipulator, and people to program the computer which controls the robot.

Now I'd like to describe some of the current robotic system applications as well as address some future developments in the area of industrial robots. Previously, robots were reviewed from the standpoint of exactly what they are. The questions are where, and how, are robots applied and just what type of manufacturing operations are they capable of performing?

One must realize, when talking about the robotic application, the emphasis must be placed on the robotic system rather than on the robot itself. A robotic system, by definition, is a manufacturing process or operation which utilizes an industrial robot. Although it is possible to buy a robot off the shelf it is not possible to buy a solution to your problem, or any other manufacturing problem, off the shelf. Probably the most important element in implementing a robot is the application technology. It is a misconception for people to think that robots have "do anything" capabilities; instead, they are limited to performing only certain operations based on their initial design consideration and, therefore, it is the job of the applications engineers to find the right places for the right kinds of robots and to make them work.

I have tried to relate to you some of the basic considerations and design procedures carried out when implementing a robot system. The need for supplying application engineering as well as the basic design engineering has prompted a new breed of suppliers into the market. Large corporations, such as General Electric, IBM, General Motors, and, of course, Westinghouse/ Unimation, are technically sophisticated and have financial,

engineering and management resources to take a much broader and aggressive approach to factory automation than the traditional robot suppliers.

Perhaps the largest present application of robots is in resistance welding. Practically all of the spot welding operations performed on automobile bodies are now being done by robots. Not only do they reduce labour costs, but robots are also capable of applying the weld more precisely when and where it is needed. This naturally improves the quality of the product as well as reduces waste. Furthermore, robots can hang upside down from the ceiling, can be mounted on the wall to help save space in the factory and to get best utilization of both the floor space and the equipment.

This is a closeup (Figure 5) showing a welding operation with the workpiece being held by a positioning table. Note that the proper positioning of the workpiece is just as important as the accuracy of the robot. Most robots today do not have the ability to detect if a workpiece is in front of them, much less know whether it is properly oriented for welding. Remember that in most respects, robots are simply blind machines taught to remember a sequence of steps and to repeat them time after time. Therefore, each part must be mounted on the positioning table exactly the same way if consistency of weld and consistency of product is to occur. This re-emphasizes the point that there is much more to a robotic system than the robot.

Another major application in today's robotics is in the area of material handling. This is an example (Figure 6) of transferring glass, for making of fluorescent tubes, from a conveyor and stacking it onto a pallet ready for shipment. You have seen some of the power of robotics and this is an area where you can also see the result of its sensitivity.

The same robot can perform a slightly more complicated operation. Tungsten bars are unloaded from a conveyor by the robot, placed into a furnace, and, when sufficiently heated, loaded into a swedging machine. This shows that some robots do not need a perfectly sterile environment. A positive pressure to keep the dirt out of the control cabinet and some bearing surface

protection have allowed this robot acceptance into both the foundry area and in the grinding and buffing industry.

There are also two arm machines used for loading and unloading presses in order to optimize time cycles when passing materials from press to press.

Spraying is yet another application. A paint spraying robot is also used for the spraying of other materials - stains, asphalt coatings, plastic powders and fluid or powdered substances. It is used to do washing and cleaning operations as well. The manipulative capability of the robot is of prime importance. Parts normally enter the spray area attached to a moving conveyor line and the robot's sequence of spraying motions are co-ordinated with the motion of the conveyor. A major benefit of robot usage is higher product quality through more uniform application of the material and less overshoot around the edges of the pot. Another important benefit is the reduced exposure of humans to the toxic materials usually involved.

Assembly operations are being performed by robots today but are limited to rather simple applications. However, with the development of vision systems and improved robot accuracy. small parts assembly is expected to be a major application for robots by the nineteen-nineties. The assembly operation shown here (Figure 7) represents some of Westinghouse's efforts in this area. The project is a program in which a robot is used to assemble the entrails of a small motor. These parts are currently assembled in batches averaging six hundred units per batch. There are thirty parts in each of these entrails and they are being assembled in about a twenty second cycle time. There are thirteen change-overs a day in order to be able to manufacture the four hundred and fifty different motor styles that are being manufactured in this plant. The advantage of this type of system is that, where change-over time was once the largest single cost, today the flexibility of this equipment allows for zero change-over time.

Computer control and sensing are the most revolutionary elements of this application. The control system is needed to handle many simultaneous tasks in the short assembly line and the

visual sensory system is required to provide the orientation of the part and the feedback. The camera for the vision system is the white device on the right (Figure 8). The vision system on this project is capable of recognizing randomly oriented parts on an assembly line after a multi-pass learning cycle controlled by an operator. It can also be used to rotate the part to any given angle.

Robots are also being used for dipping applications. This particular robot (Figure 9) unloads end valves as you have seen in the movie from a die-casting machine, doing an inspection and then doing a quenching operation.

Here is another dipping operation (Figure 10), but what we have is a robot placing trays of aluminum parts through an alumalite bath, which means it has both rinse and acid tanks down each side to provide the alumalite coating. Notice the robot is mounted on a track, allowing it to adequately reach all of the tanks.

I hope at this stage you have a good understanding of what robots are all about and how they are being utilized in industry today. I would like to quickly review some of the benefits of a robotic system.

Productivity improves. Robots are on the job every minute of every day. They don't take coffee breaks, they don't call in sick, they don't come to work with hangovers. And they don't get bored or fatigued, take vacations or qualify for pensions. They have the ability to work three shifts if desired.

Quality improves because the operations are, let's call it one word, consistent.

Long term costs are lower because you are dealing with a fixed cost rather than a variable labour cost.

People are relieved of hot, heavy, hazardous, monotonous jobs, and they **become much more productive** when used in other areas.

Incorporating a robotics system usually results in manufacturing costs with **efficiencies improvements** due to revisions in the manufacturing procedures.

Typically, the bottom line is **profitability** which will allow an industry to attain leadership in international markets.

So far we have discussed what we often call "islands of automation". What we are trying to show is that a consideration for going beyond those islands of automation is the automation of the entire factory. We have been talking primarily of one element - robots.

However, it is important to recognize that in order to make that robot successful, we have to consider also the use of other equipment normally used in manufacturing areas, such as machine tools, material handling equipment, etc. However, it is the integration of all that equipment and the ability to control those processes which have allowed us to generate at least that much automation.

In order to truly automate the entire factory, real-time feedback of both process and product information is necessary. The interface and control of hardware with the use of microprocessors and programmable controllers requires real-time status of information, and with this comes the inherent capability to interface with the information and data handling portion of the business. This allows direct input from two areas. One is the product area, where we have design changes, inspection criteria, model changes, style changes. The second area is the business input into our daily activities, such as pressing delivery schedules, inventory status, availability of facilities, availability of people, etc.

This is the area where we see the efforts in automation in manufacturing going to the full factory automation. I would like to talk about two examples of that.

Let us consider the layout of an entire factory. That factory was laid out to automatically make electrical transformers. We started from the raw material and are selecting

materials, cutting and fabricating tanks for the transformers, taking lamination steels, cutting the transformer core lamination, taking copper and insulation winding coils, operating the assembly of those operations. Then we do the test after the final assembly, and feedback that information to its preceeding operation as to when that interface should send more material. And that is the basic style of automating a factory.

We have now gone to a different level of control of that area, and that first level is control where you take any one of those work cells... take the tank fabrication.... and integrate roll straighteners, the shears, the forming presses, the welding machines, into a single control. This becomes an island of information... what we normally call a work cell in itself. That has been expanded over the years to an MC, (minimal control), a programmable control, which we call a DNC system where we have one controller - a directed numerical control that means we have one computer that sends out to the various machines, and sends out to the computers of those various machines, the programs that each of those machines needs.

We have gone one step further now, and tried taking DNC systems and tying them together with a business computer. Now the business computer can add the information on what product we need to make today and on whether production can be adjusted with material flow in order to make the product that the business computer demands or what labour forces we have available today and how we have to adjust those programs?

Those are the areas that we are looking at in factory automation, in order to end up with equipment that has the flexibility that allows a business computer to feed down the needs of the business for that particular day and allows the necessary adjustment to the operation of that equipment to meet not just our cost demands but our business demands.

Thank you very much.

Figure 1 – Robotic manipulators ready for shipment from Japan. These robots are being produced in ever-increasing numbers.

Figure 2 – An adaptable welding robot capable of handling large work pieces.

Figure 3 – A robotic manipulator used in a light assembly operation.

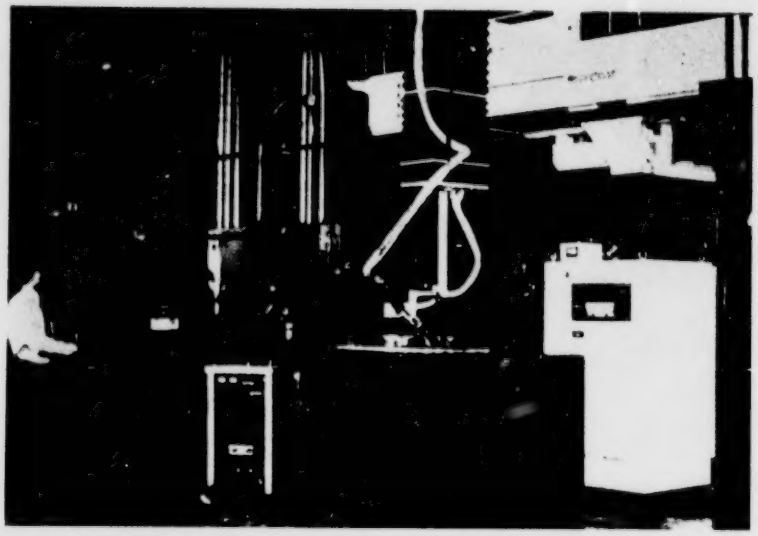


Figure 4 – A robotic machine tool with interchangeable end tool.

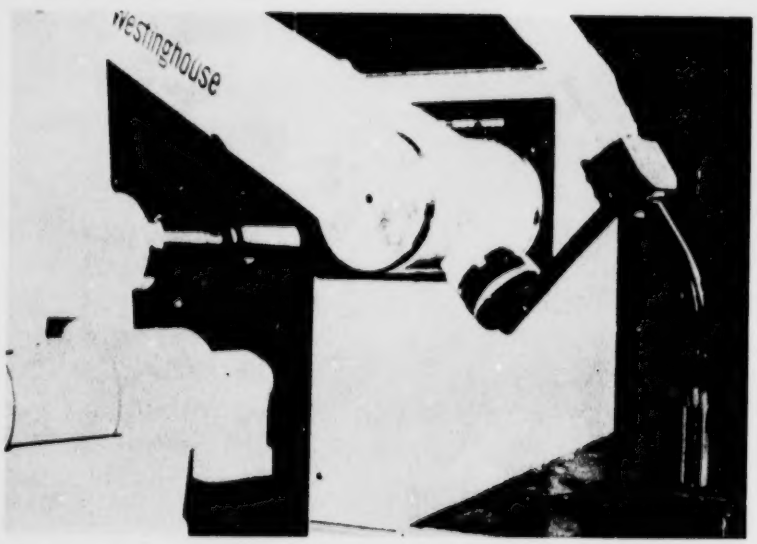


Figure 5 – A close-up of a welding robot which relies on exact positioning of the work piece.

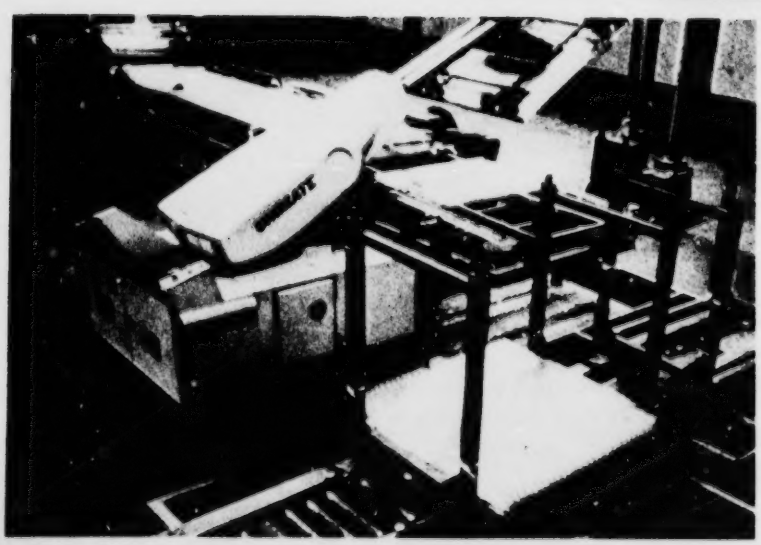


Figure 6 – Reasonably delicate operations (tasks) can also be carried out by a robot. Here glass tubes are being stacked.

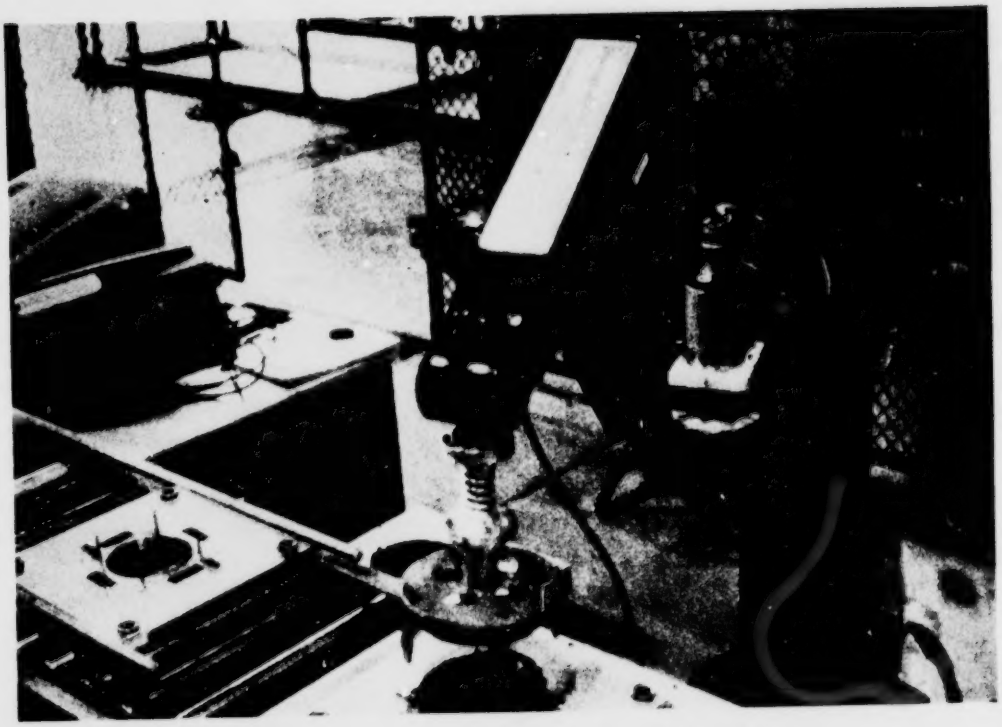


Figure 7 – Monotonous assembly operations are performaed by a dedicated robot.

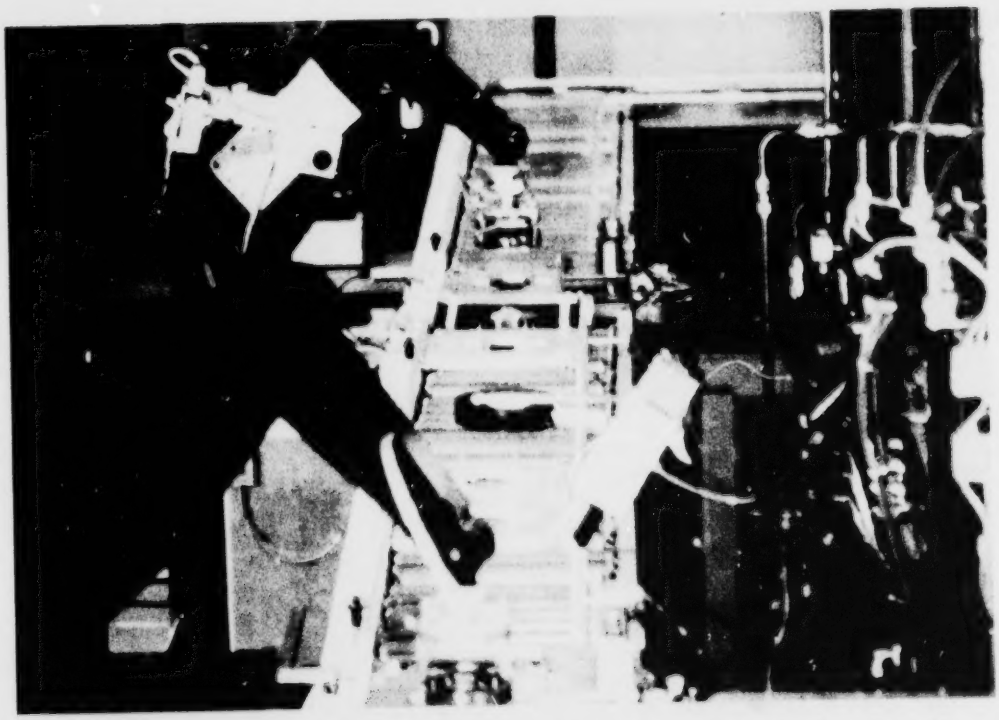


Figure 8 – A television camera interfaced to the robot's controller allows visual information to be used in decision-making.

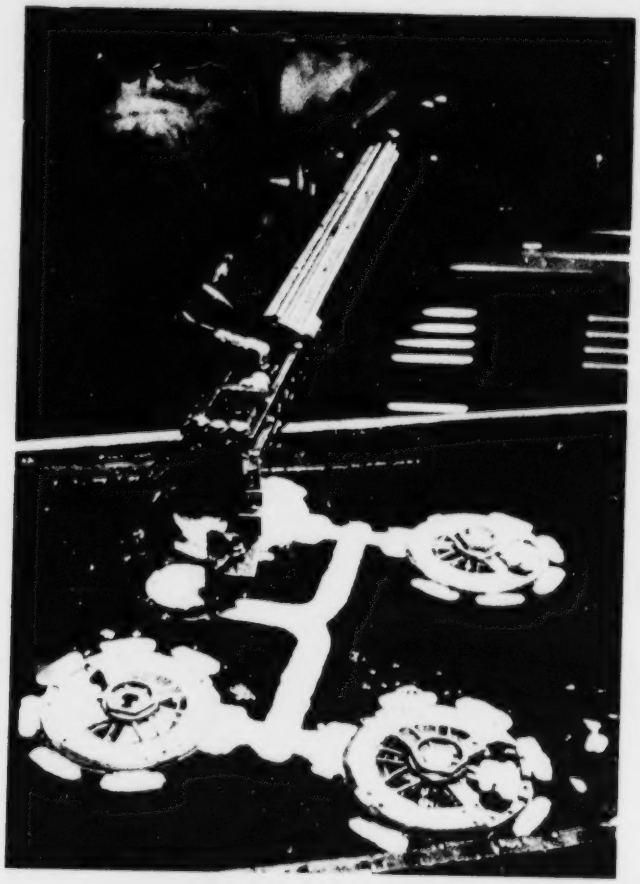


Figure 9 – Several operations (tasks) are performed by the same robot. Here inspection and quenching are carried out.

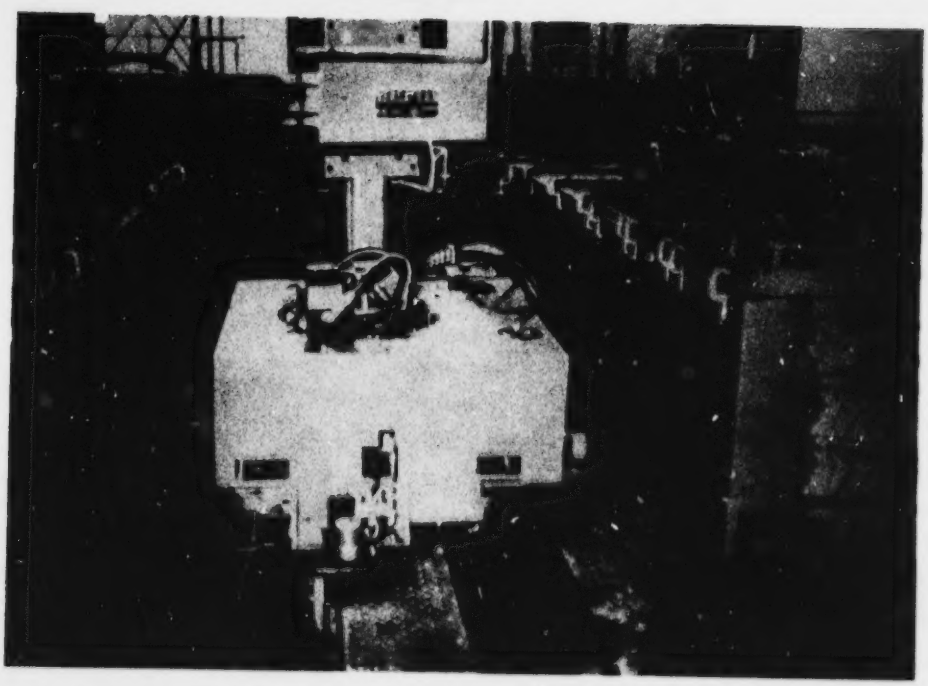


Figure 10 – Robotic manipulators can carry out work in hazardous and toxic areas such as acid dipping operations.

5. APPLICATION OF ADVANCED TECHNOLOGIES IN UNDERGROUND HARD-ROCK MINING

Dr. Jay Pathak,
Mining Research
Laboratories, CANMET.

It is generally accepted that hi-tech and advanced technology have entered the field of underground hard-rock mining quite late. They first entered into underground coal mining because of the bookish nature of deposits, regular geometry of the mining method and non-abrasive nature of coal. These features encourage trends toward automation and remote control operation. In the case of underground hard-rock mining, especially vein type deposits, it is difficult to even trace an outline of the ore body more than a few metres in advance. In one of the uranium mines we visited in Saskatchewan, the variation in the orebody was so drastic that every scoop had to be sensed before deciding whether it would go to the waste rock pile or to the mill. The ratio of the error in geostatistical prediction of the uranium content of the whole orebody to the actual mining was an unbelievably high 10:1. Besides that, the nature of underground hard-rock mining, including abrasiveness and extreme hardness of ore and host rock, unfriendly environment, face separation, and distances between working places with the inherent difficulty of supervision, make it difficult for equipment designers to make equipment for universal application. The site-specific nature of the operations tends to make robotic applications difficult if not impossible. The people (scientists or engineers) who make remarks like "mining is in the Neanderthal stage" are either ignorant of mining problems or they don't know what underground hard rock mining is all about. Repeated failure of equipment and materials makes mining engineers and mine operators pessimistic and conservative about unproven technologies.

To erode this pessimism about hi-tech and advanced technology applications, it will be necessary to demonstrate new techniques to profit-oriented operators in an environment that does not involve their responsibility from a financial point of

view but still makes them participants in these endeavours. The Swedish mining research establishement has its own research mine where they try out different aspects of mining including new mining methods and equipment. We also need such proving grounds.

In practical life, from football field to kitchen, from office to children's study room, the assault of hi-tech has been very forceful. It will be difficult to keep underground hard-rock mining in quarantine from hi-tech attacks for long. Signs of its entry are already appearing and it is time for Canadians to jump into it before we realize that it is too late.

To do a job there are a lot of technologies available, but many are neither practical nor economical. The technological limits are far broader than acceptable economic limits. On the basis of drilling technologies available, we can still drill a hole by chisel and hammer as well as by using advanced technologies like plasma piercing or particle beam. However, both ends of the spectrum tend to be unacceptable due to impracticability and/or costs. Only drilling technologies using compressed air or hydraulic power sources are within both technological as economical limits. The objective of the application of hi-tech and advanced technology is to lower the economic curve and skew it toward advanced and sophisticated technologies.

Even if we apply hi-tech or advanced technology to a process or a system, at some stage of improvement the process reaches a saturation point. Then what is needed is a radical change in the technology itself. Significant improvement can be achieved first by mechanization or improving electro-mechanical components of the system. After reaching a saturation level, there will be no further improvement in efficiency or productivity. Any further attempt at improvement does nothing but increase the unit cost.

After the first stage of electro-mechanical improvement, automation of the equipment or system could be attempted until it reaches a productivity saturation level. Then it is possible to optimize automation for additional gains in productivity, efficiency and unit costs. However, ultimately this process will also reach a dead end. Optimized automation can be best

explained by giving an example of the drilling process in mining. It is possible to automate the drilling process without optimizing it. The drill rods can be automatically changed and pulled back without human involvement. Optimized automation of this process will read parameters like rotation, thrust, rock hardness, etc. and then control all of these drilling parameters to achieve maximum penetration. Any change in basic conditions or parameters is then automatically taken into consideration so that drilling takes place at a maximum rate under the given conditions from moment to moment. This optimization will invariably require the application of microprocessor technology to such decisions.

There are series of segmented improvements in the development of any equipment or system, but ultimately this reaches a limit. After reaching that ultimate limit, what is required is a radical change in the technology itself. A good example of this process could be taken from hi-tech industry. The famous thermionic valve (tube) of Edison reached a limit which spurred research into solid state physics, giving birth to transistors and, thereby, changing the whole world of electronics.

The degree of technical development has a profound effect on input and output parameters of a system and our aim is to control these parameters to our advantage. Output parameters such as productivity, unit costs, and safety are most important for an operating company.

Primarily productivity and unit costs are very important, as well as being controversial. In British coal mines, technological development did not have a significant effect on productivity for the 80 years prior to 1960, but after that there was a gradual increase. There had been significant improvement in safety but that was probably mainly due to governmental regulation.

Because of the obvious problems with diesel equipment underground, it is necessary now to develop electrical and hybrid power systems which will enable mines to attain the flexibility of diesel equipment and the simplicity of the electrical system.

The goal should be in the direction of all-electric mines. They are especially advantageous in cold countries like Canada, where we will save not only in moving the additional air volume required for diesel HP but also in heating that additional volume. For the same power output and performance, electrical equipment needs 20% less energy input. From the point of view of maintenance - there is no comparison - according to Jarvis Clark, a 180 BHP Deutsch diesel has a total of 2776 parts of which 586 are different whereas an ASEA 180 BHP electric motor has a total of 44 parts, of which only 8 are wearing parts. Jarvis Clark has been successful in developing a trolley wire truck which has been tested underground at Fox mine.

Hi-tech is essential for such development and it should be the aim of the equipment manufacturers, hi-tech firms, and operators to achieve flexibility and reliability by eliminating diesel power from underground within 5-10 years. A similar aim should be to diminish the use of compressed air, or virtually eliminate it from underground mining. It is a very inefficient way of using energy. Presently, we are conducting a study which will stress the economics and convenience of using electrical power and pinpoint the equipment to be developed to achieve this goal.

Two major requirements of modern underground hard-rock mining are: 1. rapid drifting; 2. high volume and fast drawing of ore from stopes. Development contributes approximately 20-25% of underground mining costs. Either there should be a cheaper and quicker way of development or there should be a mining method to reduce development-to-tonnage exposed ratios.

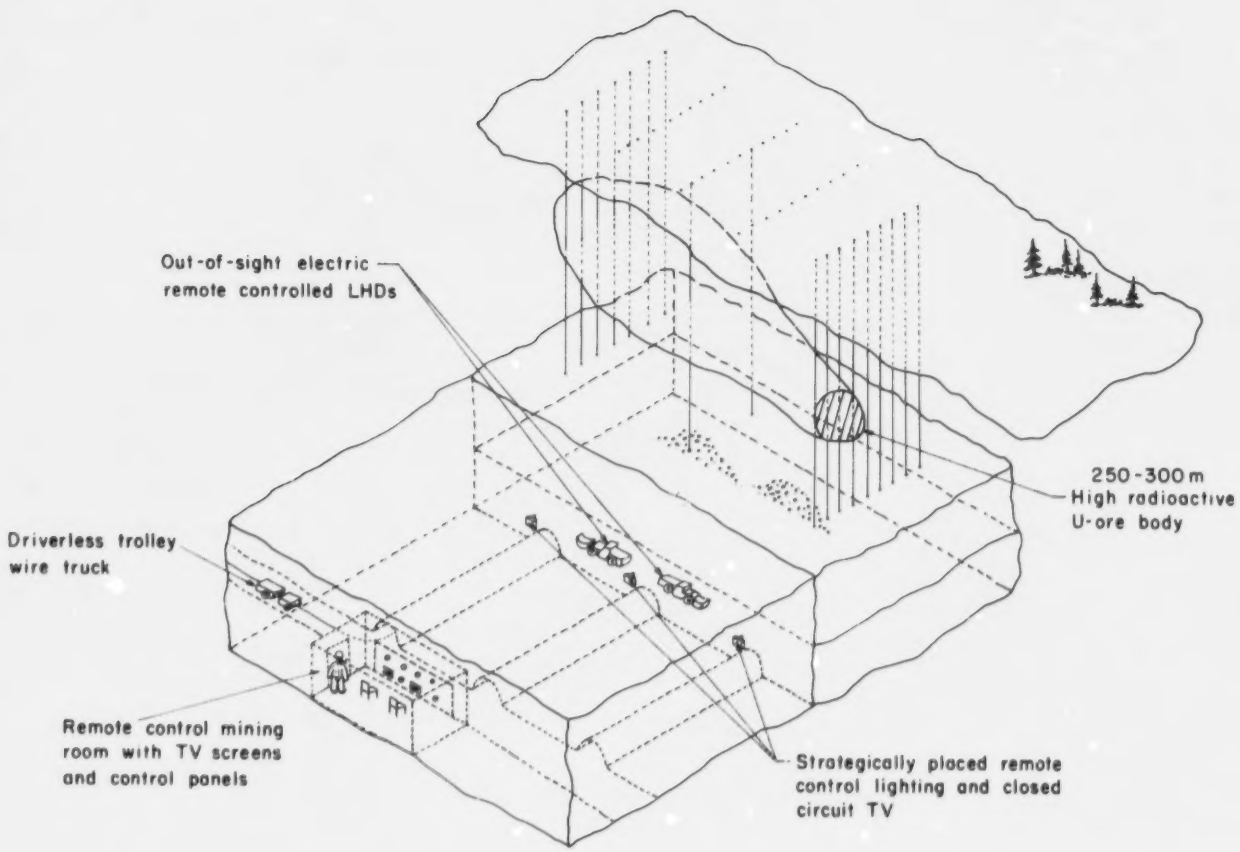
The Canadian-developed Vertical Crater Retreat (VCR) mining method has several advantages and it is expected that eventually 35-40% of the underground production will come from this method. Besides its higher productivity of about 33t/man-shift compared to 20t/ms for longhole open stoping and 20t/ms for shrinkage, it has the advantage that large muck inventories can be built up in the stopes. The present limitations to this method are predominantly posed by the equipment used to drill a VCR stope, i.e. the down-the-hole drill (DTH).

The DTH drill is a prime candidate for several hi-tech applications for enhancement of productivity. It can be fully automated so that one operator can handle more than one drill on the same sill. This will also allow reduction in the stem height resulting in low space requirement and thereby reducing the development cost. In the several mines in which I have worked, the average height of the production excavation or stope could not be more than 30 m. There was a problem with correct placing of the drill, as well as correct alignment. It was difficult to maintain the drilled hole on its planned course. Hole deviation can influence costs up to $3-4/t for operation and development losses of ore, and rock waste dilution (1).

This deviation normally increases beyond 30 m depth (2). The DTH drill needs the development of instrumentation for proper alignment, as well as on-line information on the azimuth and deviation of the drill hole. An early warning and then, if necessary, automatic stopping of drilling will minimize "off course" holes. Proper digital recorders are required to keep records of the drill rod alignment, hole azimuth and deviation, as well as drill hole coordinates. These should be in a compatible format which can be used as input to 3-D graphics, with a large blasthole simulation program. This program will be designed to depict the mining block in 3-D colour graphics, showing hole spacing plus type of strata and providing reports to the blasting foreman which contain all the information needed to carry on blasting. This program should also provide management reports and predict breakage, improving the design and resulting fragmentation of the whole blasting operation.

By using microprocessors, various drilling parameters could thus be sensed and drill automation could be optimized, giving maximum attainable penetration with minimum bit wear.

If relatively long drill holes could be so controlled, it would open up a whole new world of mining orebodies at depths which prohibit open pit mining, as well as those which present difficult technical problems for mining by underground methods. The latter situation is very common in the uranium deposits of Saskatchewan. An orebody with high uranium content can conceivably be drilled off directly from the surface.

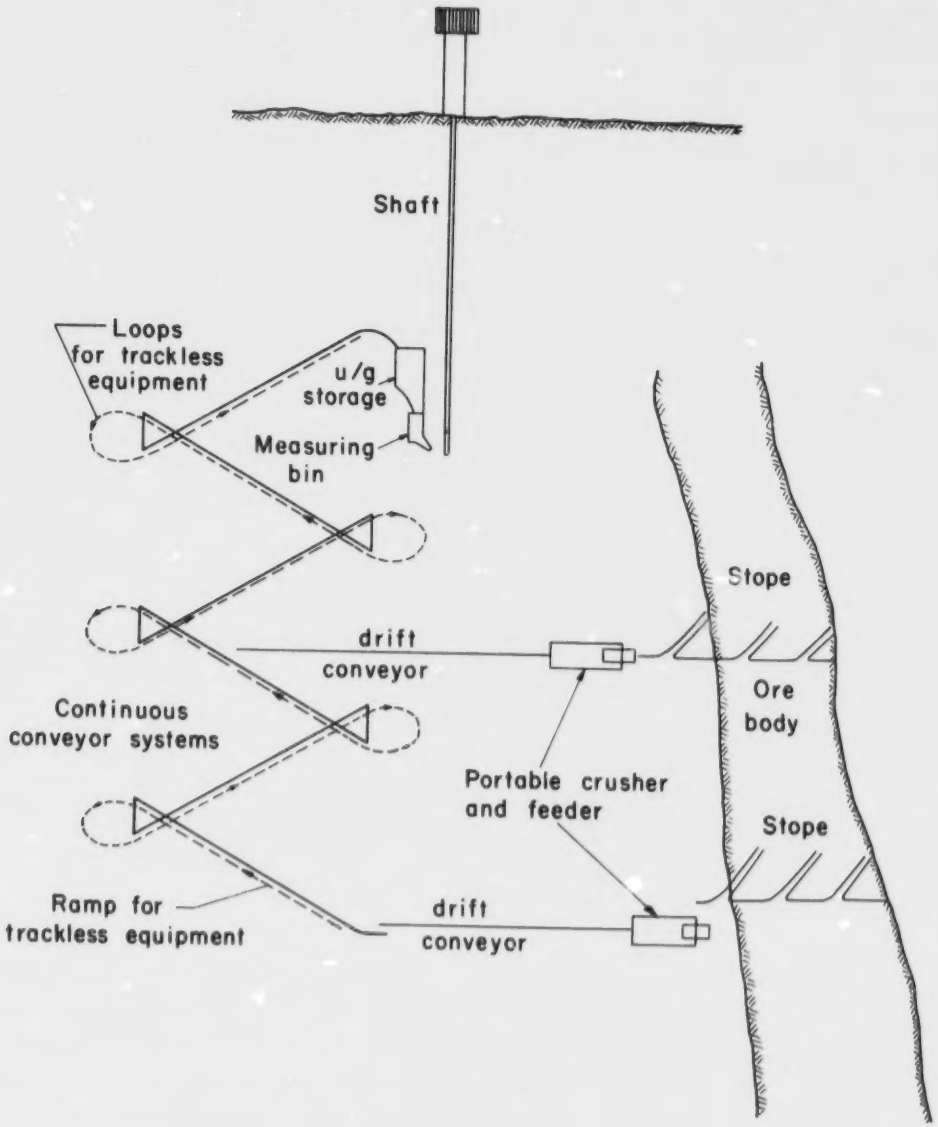


Underground hardrock remote mining.

Associated underground development could be carried out essentially without exposure to high radiation. The VCR method will drop the ore into the under-cut. Remote control electric scoop trams can then pick up the muck and dump it in driverless remote controlled trolley wire trucks or automated conveyors. This concept will need development of the technology for "out-of-sight remote control" for scoop trams, as well as trucks. Series of remote control TV cameras and flood lights, strategically placed in the mine as well as on equipment, will assist in controlling and operating these units from a radiation-proof control room. Emergencies could be handled by personnel wearing special underground suits, yet to be developed. These will be far simpler than their counterparts in space. There will be no difficulties pertaining to pressure equalization and temperature control but methods will have to be developed to make them radiation proof, as well as practical.

The advanced technology to operate "out-of-sight" remote control scoop trams and trucks seems to exist but has not yet been applied to underground operations. This will necessitate development of mine oriented "out-of-sight" remote control (or, if I may use the abbreviation, OSRC technology), as well as various training simulators. Canada is one of the leading designers and exporters of flight simulators. Accordingly, it would appear that a sophisticated OSRC simulator for underground use should be within our capability. This will be essential if we want to enter into the field of OSRC.

Continuous loaders, with portable crushers and conveyors, conceivably could remove broken ore or waste rapidly from excavation operations. However, conveyors cannot be used unless they are fed with relatively small sized material. Presently we do not have portable crushers of suitable size, with the capability of conventional underground crushers to break ore and waste rock of the Canadian Shield. A conveyor system can rapidly remove material from stopes. The same system, if properly crushed waste rock is available, can be modified to backfill empty stopes. To realize this concept, loop conveyors are available but there are still no practical crushers developed which are small, light, truly portable and can crush 35-40,000 psi rock. In crusher design and development, we appear to have reached a



Schematic of hardrock portable crusher and underground conveyor layout for intermediate transportation.

dead-end, although USBM is currently conducting such a development project and now, with CANMET assistance, being tried at INCO. What we need is a radical change in crusher technology, possibly utilizing a different kind of energy to break rock.

CAD/CAM systems or Computer Aided Engineering has become a very powerful tool in the manufacturing industry and it is now getting within reach of even small manufacturing companies. There are several similar systems available for open pit mining but in underground hard-rock mining they are still at the initial R&D stage. Some pioneering work in the field was done by Kidd Creek Mines in Timmins in the early 70's. An update report was written in November 1981 by McManus and Walasek (3). Their remarks on such systems follow:

"It can be said that even after eight years, 3-dimensional interactive graphics have not been fully accepted as an everyday tool of mine engineering at Kidd Creek. They are viewed by most as R&D work, rather than as a viable and efficient means of manipulating data and conveying information."

Some graphics programs for underground mining have also been developed by Queen's University but these are still far from the application stage.

Development of a compatible planning system on a computer is an enormous and expensive task. To be successful and acceptable to mining engineers, the system has to be developed following the same sequence of thinking as is done at the operating mine and the results should be realistic and usable in practical operational situations. Delayed entry of such a computer aided engineering and planning system reflects the complexity of underground hard-rock mining. This is reinforced by the conservative attitude and traditionalism of the mining industry. A viable plan should start with geological plans and sections to form a 3-D illustration of the orebody with which a mine planning engineer can "play around", not in terms of numbers but in terms of lines and pictorial figures. Once he is satisfied with the layout, the rest of the work should be done as 'donkey work' by the computer, producing reports and plans which could be handed out to surveyors and operational staff for implementation. The

proposal appears both simple and ambitious but it may be expected to be a very formidable and expensive task.

Communication in underground hard rock mining is still not adequate. At any time, there are normally not more than three persons within sight of a firstline supervisor. The low density of labour per working place makes it difficult to get immediate help in case of an emergency. There is no paging system available for key personnel underground. I think only one mine in Canada has a walkie-talkie system underground. Compared to modern communications available on surface, communications are primitive.

To take over end-of-the-shift routine reporting by the shift bosses, it might be advantageous to develop a Mine Status Indicator (MSI) which differs from a mine environmental monitor controller, although they both could share the same central processor. The MSI could eliminate the time lost by shift bosses in collecting such data. This data is required for calculation of car factors, manpower distribution, allocation of work and production scheduling on a day-to-day basis. The following is a preliminary list of what a MSI should measure, producing a hard copy report for management:

- all ore pass levels (tonnes);
- all waste pass levels (tonnes);
- all finger pass levels (tonnes);
- number of skips hoisted during the shift (tonnes);
- number of tonnes of ore and waste hoisted in the shift;
- on/off status of each pump;
- sump levels;
- mobile equipment distribution;
- ore and waste car counts;
- car distribution;
- weight of each car and where it was dumped;
- conveyor running time and tonnage delivered;
- fine bin levels;
- distribution of manpower with location;
- radiation levels by location (if applicable);
- etc.

Mine Environmental Monitors are being developed in Canada, as well as abroad. At present monitor and control systems are available for coal mines although only monitor systems for hard-rock mines. Sensors to detect methane, CO, temperature and air velocity are well developed and proven, while sensors for CO_2, NO, NO_2, SO_2 and particulates have also been developed but not yet evaluated.

A ventilation monitoring system, developed by Rantech Electronics (4), has been tested at Kidd Creek Mines on one production level. It has already proven to be a useful tool in ensuring an efficient, productive workplace. Knowing the airflow requirements on weekends and manually adjusting them has contributed to considerable savings in mine heating bills. In the literature (5), it has been reported that Outokumpu Oy has developed and installed a ventilation monitor as well as control system with microprocessor controlled ventilation doors, fans, regulators, etc. They have resulted in 25% less requirement of intake air and 45% saving in heating cost. A whole mine environmental monitor, as well as controller, is a domain where the efforts of hi-tech should be directed, especially where winters are severe. An underground uranium mine, in addition to the above development will also require radiation monitoring and control.

Automated and microprocessor controlled scales, electro-hydraulic jumbos and raise borers are now being built or they are undergoing tests.

This paper has attempted to indicate some areas with potential for the application of <u>hi-tech and advanced technology in underground hardrock mining</u>.

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6. POTENTIAL USES OF ROBOTICS IN MINING

Henk van Deudekom
Innes P. Grantmyre

Vadeko International,
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Vadeko has had an interest in mining ever since it started operations two and a half years ago. However, in that direction it had to wait until the firm was on stable footing.

Early this year we judged the time was right. We were fortunate in attracting the attention of a person who had been involved in the development of mining machinery for some twelve years at Joy's Advanced Development Centre in Cambridge, Ontario - Mr. Innis P. Grantmyre.

He helped us in formulating a strategy that will become apparent a little later. Notwithstanding his presence at Vadeko, I feel a little strange in talking about a field of engineering, mining, that - while fascinating - is essentially foreign to us.

I beg your indulgence if I seem to be an outsider, which I am. The mining companies we have spoken to have been most hospitable. They have displayed great patience in showing us around on their properties and in explaining their current method of operations. My observations are based on visits to half a dozen underground mines and discussions with numerous mining people.

While impressed by the sheer size of the equipment and scope of the operations, I believe, with many mining people that I met, that there is considerable scope for improving productivity by introducing the kind of technologies that Vadeko is familiar with and competent in.

That begs the question of who is Vadeko and what does it do.

Vadeko started operations on February 1st, 1981, to pursue the commercialization of the technology developed for the Canadarm, Canada's contribution to the U.S. Space Shuttle program. The principals, Dr. Whitehead and myself, had been involved with that project for a number of years and felt that there were many fields where the technology could be fruitfully applied.

The company's main thrusts are therefore, System Engineering, a methodology oriented activity and the engineering including research, development and manufacture of electro-mechanical systems that substitute for, augment, and/or automate human capabilities. This encompasses broadly the field of industrial automation and robotics.

We are in the process of establishing a presence in four industry sectors, namely, nuclear, manufacturing, mining, and marine, and have scored modest success in some of them.

Over the two and a half years existence of the firm we have assembled a team of very competent engineers, designers and technicians with a range of skills that permit us to undertake development projects from concept to hardware.

In observing the mining scene, we naturally look for some analogy with the processes with which we are familiar, namely those used in manufacturing.

Canada, like many other countries in the western world, has been given quite a jolt by the emergence of Japan as the manufacturing country par excellence; a status it gained through hard work and shrewd application of offshore technology, notably from the United States.

The secret of the Japanese lies in the innovative use of automation, flexible and hard, to produce high quality consumer goods at a competitive price.

To counter this threat, North American industry has responded in kind with the wholesale re-industrialization of important industry sectors such as the automotive sectors through the introduction of automation.

The general malaise over the past four or five years has brought with it vastly reduced demand for base metals. The policies of resource-rich developing countries have led to market anomalies that have seriously affected our domestic mining industry.

The response of the more progressive companies has been to seek ways and means to make our mines more productive and automation will play an important role in achieving this objective.

Mining is a capital intensive operation and the lead time to bring an orebody into production may require up to eight or ten years. Consequently, the pace at which new techniques can be introduced is necessarily slow and ponderous, and as a result the industry has been accused sometimes of being overly conservative.

The nature of a particular orebody has a decisive influence on the methods employed to secure its successful extraction. For example, open pit versus underground cut and fill mining versus vertical crater retreat, etc.

Furthermore, the mining company has to respond to social concerns, such as the safety of its personnel, the minimization of environmental despoilation, the quality of work, minimum wage laws, etc.

The above factors all imply constraints that affect the economics of ore extraction. In parenthesis, this is nothing new to system engineers; they are accustomed to devoting much attention to environmental constraints surrounding a problem.

My comments on the potential for automation, in particular robotics, to mining are necessarily limited to the production phase of the mining cycle.

In the preceding exploration and development phases there are other imperatives. I am thinking particularly about the latter, where one would like to minimize the elapsed time to bring a mine into operation. Here the imaginative use of computer-aided design would also serve to establish a useful database for optimization of production. I am inclined to believe that this new design tool might materially reduce the time to bring a mine into production which, considering the capital that's tied up and the fickle nature of the world economy, is worthy of further examination.

Mines are expected to produce for many years and will have to endure the ravages of many a business cycle. There seems to be a need, therefore, to build into the production system the capability to respond effectively to variations in demand without causing major social disruptions. Increased automation would appear to be the answer for future installations and possibly present ones.

The focus of my talk will be limited to automation of existing mines. Progress achieved in sensor and microprocessor technology and the application of advanced control engineering concepts will permit significant gains in productivity and return on capital investment.

To be more specific, what are then the needs as we at Vadeko perceive them? In order of increasing complexity:

- improved equipment availability
- extended equipment life
- enhanced productivity.

Mining machinery is both expensive to purchase and to operate, e.g. an LHD of modest capacity will run about a quarter million dollars to acquire and half of that in annual operating expenses. The selective monitoring of operating parameters and machine functions will enable prediction of the need for maintenance of specific components and timely detection of incipient failures.

It requires the introduction of sensors, an onboard microprocessor with sufficient memory and peripheral hardware/software external to the machine to periodically collect, process and analyze the data generated. If experience in other industry is anything to go by, the potential cost savings of changing from maintenance at some fixed interval to maintenance as required, will be substantial. Adoption will see an effective reduction in maintenance activity, parts consumptions, spares requirements, improved maintenance scheduling and reduced manning. The uptime or availability of the machinery will be significantly improved.

Going a step further and adding controls to the sensors and microprocessor will permit one to override the commands of the operator as required to ensure that the equipment is functioning within its design limits. Production incentives frequently motivate the operator to exceed the capacity of the machinery. This increases the need for maintenance and reduces the life of the equipment. Modern technology provides the means to put an end to this practice that is essentially counterproductive from both the operator's and the mine owner's point of view.

Finally, close examination of the equipment function will indicate ways whereby, through the automation of selected tasks, important manpower reductions can be

effected. There is a view among people in the mining industry (and other industries) that certain activities require judgement that only a human being can supply.

Judgement involves the conscious and sub-conscious interpretation of events based on one or more previous observations as to cause and effect. In most instances, if properly analyzed, algorithms can be found that reproduce human reasoning.

The facts are that sensor technology has advanced to a state whereby, coupled with the processing and interpretation capability of a computer, these algorithms can be implemented and, thereby, human judgement be supplanted by machine.

Automation brings with it many important improvements in operation, e.g. the equipment is always functioning in an optimal manner, thereby maximizing output, it is operated within its design limits, resulting in increased reliability. In short, the equipment is always operated as the designer had intended, thus bringing out the best the machine has to offer.

The connotation individuals attach to the word "robot" varies from R2 D2 to E.T.; for our purposes today, however, I will observe the definition proposed by the Robotics Institute of America, which reads as follows:

> "A robot is a **programmable, multi-functional manipulator** designed to move **material, parts, tools** or specialized devices **through** various **programmable** motions for the performance of a **variety** of tasks.

Earlier in my talk I mentioned the words hard and soft automation. What is meant here is the degree of flexibility that the automatic set up permits. For a company like Honeywell that produces hundreds of thousands of wall-mounted thermostats, it makes sense to design automatic assembly fixtures that are only suitable for one

style of thermostat. The automation is hard. For smaller quantities of an item that is marketed in a number of different versions, e.g. a television set or a dishwasher, flexibility is required in the automatic setup to accommodate the various configurations. The automation is called soft.

In a similar vein we make a distinction between batch and continuous production. Where quantities permit, such as the thermostat example above, we find that hard automation is associated with a continuous process. For production of small batches where flexibility in assembly techniques is required, programmable devices such as robots offer considerable potential.

Applying this philosophy to mining, where one deals with what is essentially a continuous process, the application of robotics in the sense of the definition given above is limited. In our research to date, very few good examples have come to the surface. However the skills and know-how that underpin robotics; i.e. control engineering, sensor and microprocessor technology, and the system approach, are also the key ingredients to achieve the objective of satisfying the perceived needs enumerated before.

Our discussions with mining personnel have revealed some important, real and imaginary, obstacles to the introduction of automation.

It is understandable that the introduction of new technology is a slow process. Mining conditions are aggressive and hostile to hardware. Equipment is subject to dust, shock, vibration, temperature extremes, humidity, rough handling, etc. Companies are reluctant to venture into the unknown. So how do we establish a track record? Could CANMET play a role?

Equipment needs to be serviced. The skills needed to support automation are likely to be different from what is currently available within the mining community, suggesting the need for retraining and increased field service support by suppliers.

Another, more imaginary obstacle to the wider use of automation was mentioned already the lack of faith in replacing human judgement by the computer.

It is clear, however, that changes are in the wind. For example, INCO will be opening up the North mine as a research mine. Falconbridge, Noranda, Kidd Creek and Inco have organized a joint venture to undertake research and development programs. A vehicle to finance promising machinery development projects has been set up under the name of the Ontario Centre for Resource Machinery.

Recently CANMET has sponsored two important studies: the one conducted by Robertson Nickerson, and the joint study with Monenco performed by Drs. Pathak and Muirhead. If the purpose of these two initiatives was to stimulate Canada's mining industry to critically examine its future, I believe from my limited observations that they have hit the mark.

The greatest stimulant, however, must be the balance sheet. For some companies and the communities in which they are located, what is at stake is survival. With no relief in sight that will improve the economic climate, serious consideration is being given to what new technology has to offer. We see a change from a technology-push to a market-pull situation.

Here is an opportunity for Canada to strengthen its position in the mining equipment supply market and displace some of the imports. The possibility of retrofit of automation on existing Canadian machinery creates an instant export market to those countries where the same equipment is being used.

To come to grips with the problem one must initially concentrate on the overall system employed to perform the mining process, determine its overall requirements, examine how advanced technologies can help in finding solutions that will improve the productivity and support research and development in these areas.

To achieve smooth functioning, control at various levels is required and this introduces a need for a hierarchy in the control structure based on principles not unlike those used in the administration of large organizations. Each level relates to the next higher level problems it is unable to solve, decisions beyond its authority to make and, periodically, its status.

Successful automation relies on the extensive use of sensors and the real-time processing of the parameters sensed. To co-ordinate the various functions and achieve harmonious operation supervisory control is indicated.

In conclusion, I would like to provide some concrete examples of automation as it is currently practised around the world and confirming our perception of the needs of the mining industry.

Increased equipment availability through monitoring of selected performance parameters:

* Magma Copper's San Manuel mine has installed a mine-wide monitoring system which gathers and displays the status of all major electrical equipment such as switchgear, rectifiers, pumps, ventilation fans and air compressors. The system also monitors underground air flows and gas levels for fire precaution and fire fighting purposes.

* The U.S. Bureau of Mines has developed a computerized instrumentation system for monitoring the performance of a 24 ft diameter blind shaft boring machine. Two data acquisition subsystems (one located on the surface, and the other on the machine itself) provide for measurement of 48 individual parameters covering guidance, machine alignment, machine "health" and general performance. It has operated on-site with only minor problems.

Extend equipment life through load sensing and control of operating variables within the design limits:

* Hydraulic drill systems have achieved exceptional footage from drill bits and steels. In part because of automation features which optimize rotation and thrust in changing rock conditions.

* Similarly, a computer controlled raise borer is reported to have been highly productive in a Canadian mine.

Improve productivity through automation:

* Automatic train system such as the one installed in LKAB's Kiruna mine in Sweden.

* A Marietta continuous miner has been automated for use in a Saskatchewan potash mine.

* The Phelps Dodge Corporation has automated truck-shovel dispatch at its Tyrone open pit operation.

The preceding examples illustrate incorporation of new technology with varying degrees of success. All are progressive in character. The restoration of good health to the Canadian mining industry will require more widespread application of similar techniques over the years to come.

7. CANMET ACTIVITIES, PAST AND ANTICIPATED

Mr. David B. Gladwin
Assistant Director, Mining
Research Program Office, CANMET.

CANMET has had an awareness of potential application of robotics, remote manipulators and automation for several years. I speak of it as an awareness rather than a direct thrust in that it is something which has evolved from many sources within the laboratories. We have had scientists and engineers working in many areas of mining, mineral processing and metals research, and gradually we have been building concepts for productivity and safety improvements, from general implementation of higher levels of electronics technology in the industry.

Our early interest led to the contracting out of two key R&D studies, both of which have been mentioned by previous speakers. These two studies - one by Montreal Engineering on "Interaction of Potential Developments in Mine Equipment and Mine Design", and a second study by Robertson Nickerson relating to "The Identification of Potential Applications for Robotics and Remote Control Systems in Canadian Mining", have contributed significantly to the formulation of our strategy for an R&D program related to robotics in mining.

By way of brief digression, I note that both of these studies have been, by the way, what we would consider to be best sellers. There has been an extremely high degree of interest from the private sector and government agencies, both within Canada and beyond. I would like to think that the interest generated by these studies is an indication that the findings and recommendations are contributing to the development of further applications of this technology beyond our programs.

One particular conclusion we realized after these studies, and again it's a growing thing, has been that application of robotics technology in mining, or mineral processing, or metals, or any industry, does not happen suddenly. We do not need to think of a robot per se. We do not need to think of robotics as meaning a total change in mining systems requiring us to depart from the current cyclic operations of drilling, blasting, mucking, ground support and conveying, and perhaps even on through mineral processing, making it all one comprehensive operation for one robot underground.

In fact, a key understanding we reached was the recognition that there is a series of technological stages towards application of robotics. This process starts at manual process control - which is where we have individual labour action, maybe extended by basic machines.

Currently this is demonstrated in basic mining operations such as drilling by jackleg. The next stage of the process is implementation of mechanization, involving initially the use of basic mechanical equipment progressively becoming more complex and sophisticated and which extend the capacity of an individual operator who must, however, be on the machine and who must control it. Basically it's one man, one machine; or more than one man, one machine. Again, in examples from the mining side we have LHD equipment, drill jumbos, open pit shovels, crushing plants, etc. The examples are numerous.

Moving on to the next stage, we are beginnning to get the operator off the machine through implementation of remote control. This may eventually enable one operator to extend his capability to more than one machine. Again, there is a potential for dramatic productivity increase. But these systems are still reliant upon the skills of one operator to observe and to control all machine functions. In mining we now have examples of that in remote controlled scooptrams, some raise boring. This technology is perhaps better implemented however in the processing plants with the central control.

The next stage towards robotics is the development and implementation of monitoring capability to automatically and routinely sense operating parameters in the work place. It is then a gradual technological shift from just being able to sense these parameters to implementing responses to these parameters as automatic operation controls. In the mining sense, the initial stages of automatic control are evident now in ventilation systems, crushers, and conveying systems.

Robotics can then develop by progressively increasing the combining of monitoring and response capability with the machine control capability through application of programmable logic control.

It was essential for us, at this stage of our R&D program development, to examine the industry to see where the technological capability existed, and to see where CANMET's role in robotics might be. Coincidental with this process, CANMET was asked to prepare an overall review of all of our work and our mission in minerals R&D, including mining technology. A basic requirement of that review was the preparation of a series of background studies on the state of technology and needs of the key mineral industry - mining, mineral processing, and metals.

We were fortunate in that we were able to piggyback the assessment of potential application for robotics technology onto the more general overview of our broader study. This helped us to achieve a better planned program for applications of advanced technology in mining within a tighter schedule than if we had carried on in a more normal evolutionary research manner.

Out of this process, we were able to evaluate the levels of application of robotics through the industry and to use these evaluations as part of a base for us to formulate an ongoing research program. In general we found that there are examples of very high levels of application of robotics in the industry and there are examples of actual nil application. Some parts of the industry are heavily dependent on manual process control operations. I mentioned

examples before in mining, such as scaling, or drilling with jack legs, etc. A substantial proportion of our mineral production today still depends on manual operations. In general, however, in almost every operation, every mine and mill, you can find fairly well advanced application of mechanization for some aspects of their process.

In the past decade, plus or minus, there has been a lot of talk of mechanized mining, which is basically the move to dieselized equipment. I think that has been well implemented and we have achieved a high level of productivity gain through that. The industry can now look at going beyond that, which leads to applications of remote control in mining. We do have some remote control applications in mines. There are remote controlled scooptrams, for example.

We also have general capabilities for monitoring systems which form the basis for automatic control. The central monitoring systems in general are developed. We also have the computing capability and software. But we are obviously lacking in sensors. We do not know everything which we need to sense and we do not have adequate sensors for many already identified parameters. We are developing these however.

I think automation of operations is coming. It has very little application at present on the mining side but it is very well developed in the mineral processing plants and in the smelters. I think that there are reasonable mid-term objectives for the whole industry in applications of automatic control.

At this time there is very little application of what we might truly call robots in mining. I think that such technology is a long way off, however, it is a reasonable long term R&D objective.

The foregoing presents some of the conclusions and evolutionary aspects from our past work. From that background, and drawing heavily on our contacts with industry, we have assessed priorities for specific industry needs and we have developed a specific R&D program to address

these needs. The current program is largely implemented by contracting out. CANMET does not have the resources to launch a substantial in-house effort, nor, I think, do we want to pursue this extensive type of work in house. We prefer to cooperate with industry on this heavily equipment-based technology. Many of the R&D contracts that make up the current program related to robotics have been initiated following the submission of unsolicited proposals from industry and other interested research groups. The majority of the sucessful proposals have had substantial industry support. Where we have accepted unsolicited proposals and issued contracts they have been judged to be complementary to our program and they also have met Treasury Board guidelines for acceptance. That, of course, is essential for contract work to be approved.

The basics of the current CANMET program, which is a blend of in-house and contract work, is along four avenues.

1) First, we have ongoing assessment of industry need and potential for robotics. This is a continually evolving program as the subject is by no means settled at this time. We expect it will continue to grow as robotics-related capability grows. At this time, we have two specific contracts in place on this work.

   The first one of these is a contract with Canadian Mine Services. CMS are carrying on with a second phase of the Monenco Study to evaluate the potential future impact of new equipment technology on mine operations and design. They are going out to the mines and talking to people there. They have probably already interviewed many of the industry people who are here today, and they are finding out the industry comments, through its operators, about new applications of electronics technology in mines and about how these may affect their operations. Peter White from CMS who is their prime contact on the job, is here today. He will be willing to talk to interested parties about the current study after this morning's session.

A second current contract aligned along the current general thrust of developing our program, is one with Queen's University Mining Department. This contract study is assessing the current status of mine equipment maintenance systems, another key need of any potential application for a high technology in mining. As more complex and sophisticated equipment is installed in mines, it must be able to be maintained in the prevailing harsh operating environment. This study combines both a literature status review of maintenance systems and a status report on the applied mine maintenance systems currently used across Canada.

2) The second thrust of our current program is the development of a specific equipment capability in areas where there is a pressing need. This work again largely is comprised of contracted-out R&D. The contracts in this thrust have all arisen out of unsolicited proposals which have had strong industry support. I will list five of them very briefly.

The first one is with Teledyne. They are developing and building a prototype mini-hydraulic scaler/rock bolter. It will, we hope, have immediate and significant impact on scaling operations which are now largely done manually in a dangerous environment.

Inco has a contract to develop and to produce a prototype bar-and-hammer robot. The initial objective of this device is to punch tuyeres in a copper converter. It is an operation which is very unpleasant and hazardous for human operators. The idea of a mechnical device for this work received a lot of sympathy around the government circles. We hope that this bar-and-hammer robot will find later application in other tasks around mines and mills, such as scaling, clearing conveyer transfer points, etc.

The third and fourth contracts are not direct CANMET contracts. They are contracts which we have sponsored and provided technical assistance on and for which we have been able to lever our limited resources by tapping some far greater wells, at NRC and the DSS Source Development Fund. These two contracts are the development of a tunnel boring machine (TBM) by Lovatt Tunnel Equipment Inc., and the development of an erector-transporter to work with the TBM by Beaver Equipment Ltd. Both of these contracts are related directly to rapid drivage in coal mine strata. This work has led to the development of the first Canadian rock boring machine which is currently in operation in Sydney, Nova Scotia.

Apart from the initial use of the erector-transporter to take apart the tunnel boring machine, we hope that it will find other applications elsewhere.

The fifth current contract in specific equipment development is in negotiation. It will lead to the development of a prototype down-the-hole drill control and logging system. Through this contract we hope to demonstrate the capability to automatically change drill stems and to log and control the drilling parameters so that drilling performance is optimized while not exceeding machine component capabilities.

3) The third thrust of our current program is the development of greater mine design capability. A primary effort in this area is a contract with Mining Resource Enginering Ltd. of Kingston. Jay Pathak mentioned some aspects of this contract in his talk.

They are developing an interactive, user-friendly, blast-hole explosives loading, software system. This will allow blast planners and foremen underground to greatly improve explosives loading capabilities, especially considering the variabilities in the drilling alignment with the long bore holes needed in vertical crater retreat.

4) The fourth and final thrust area which we are currently pursuing, is that of operational monitoring and control systems. This thrust is related directly to the ongoing development of sensors, for key operational parameters. This leads, in the mining side, towards mine environment monitors to pick up diesel exhaust, airborne dusts, noxious gases underground. This has been a continuing effort on CANMET's part primarily through in-house work, but supported by contracting out specific components.

A second emphasis here is on the simulated processing of ore and coal. This project has brought together a large number of parties from industry and government research agencies and it is carrying on. We hope next year to have a demonstration in a coal preparation plant of a part of the full SPOC package.

In closing, CANMET has an awareness of the potential for application of robotics in the mining industry. We have an evolving active program. It is by no means fixed or static. The program is a blend of in-house and contracted-out projects, involving many industry partners. Meetings like today are of great benefit to all of us for the essential interaction and feedback on our specific projects and where we might go next. We look forward to responses from the people here, either directly after the meeting or later on, in helping us to further develop robotics technology relevant to the mining industries. We invite those who have specific interest in this kind of research to be in touch with the scientists here. Thank you.

8. IMAGE ANALYSIS SYSTEM AS A MONITOR FOR COMPUTER CONTROL IN MINERAL PROCESSING PLANTS

Dr. W. Petruk
Mineral Sciences Laboratories
CANMET.

Dr. Mainwaring asked me to cover the topic of robotics in mineral processing as a result of a discussion that we had on integrating an image analysis system into a mineral processing plant. Upon reflection, I realize that CANMET would be better represented by someone like Dr. Laguitton who works full-time on computer simulations and mineral processing plants. I direct those who are interested to Dr. Laguitton.

Because of my limited knowledge of mineral processing, I will limit my discussion to computer control by image analysis of a mineral processing plant. This topic was brought to me by an ore dressing scientist about eight years ago when he asked whether I could see any possibility of using image analysis to classify mineral grains on a belt that feeds ore to a plant circuit. He proposed that if a grain were identified as a desired mineral, and if it were a free grain, it could be accepted by directing it with an air jet towards a concentrate. We are now much closer to this objective than we were eight years ago, although we are still far from it.

On the other hand, computer control in mineral processing plants is not new, and the day is rapidly approaching when the use of computer control in concentrators will be a necessity. This control will eliminate the fluctuations that occur in manually controlled plants with the result that higher recoveries and more or less constant concentrate grades will be obtained. On-stream analysis by x-ray fluorescence has been used for many years and is now standard equipment in most plants; materials balance using the MATBAL program of Dr. Laguitton with a PDP 11 or similar computer are now commonly used; computer control of the grinding circuit is frequently referred to in the literature; computer control of the flotation circuit is installed in some plants.

The computers in the plants control the operation of such tasks as reagent additions; opening and closing valves to adjust the flow of water, air or slurry; turning pumps on and off, changing impeller speeds and other similar tasks. The measurements that are made to initiate the controls are the on-stream XRF analysis for element concentrations, measurements of pH, density of slurry, flow rate, grain size analysis and other measurements. The objective of the concentrator, however, is to concentrate free, or nearly free, grains of specific minerals and to obtain high recoveries of these grains. Therefore, it is desirable to have a means of identifying the minerals and measuring the mineral liberations in sample from judiciously selected points in the circuit. No such measurements can be made routinely at the present time. An automatic image analysis system can, however, provide this measurement, and it is possible that it will become a standard measurement in the future.

This automatic image analysis system would have a scanning electron microscope as a front end. Polished sections of the sample would be mounted in the scanning electron microscope, and an image of the grain in the polished section would be obtained. The image would be sent to an image analyser which would outline each grain and determine, on the basis of grey level, whether the grains are free or middling particles. The image analyser would steer the electron beam of the scanning electron microscope to individually scan each free grain and each phase in the middling particles. The spectrum from each phase would be directed to an energy dispersive x-ray analysis system which would sort the spectrum into elements and compare it to a mineralogy file to identify each grain. The identification would be sent to the image analyser which would match the grain identity to other parameters that have already been measured for the grain. The goal of this measurement is a maximum of two seconds to analyse each grain, thus about 1800 grains could be analysed in one hour, and a statistically valid set of data would be obtained in two to three hours. The magnification would be selected so that each field would contain about 100 grains. When analysis of the field is completed the stage would automatically be moved to a new field. At the end of the analysis a printout would give mineral quantities, per cent of each mineral as free grains, sizes of

free grains, sizes of middling particles, and sizes of inclusions in middling particles. At the present state of the art the analysis is automatic from the time that the image of the first field is obtained on the scanning electron microscope.

If the turnaround time per sample is three hours, eight samples could be analysed in a 24 hour period.

We believe that on-stream mineralogical data obtained for up to four points in a plant and correlated with on-stream XRF analysis which are taken every ten minutes would provide invaluable information for the computer control of the plant. This is because any changes in the ore or in the plant operation will change the proportion and sizes of free and unliberated mineral grains. These changes would further modify plant operation. In many cases these changes cannot be detected by the on-stream XRF analysis. We, therefore, believe that the concept of automatic mineralogy will provide a very sound basis for mineral processing plant control, but this concept still needs to be tested. We are not alone in this belief. The researchers in the chemical engineering department of CSIRO in Australia have reached the same conclusion and are actively testing the concept.

At CANMET we are in the process of putting together the image analysis system that I just described as part of the START program. We expect to be able to provide much needed mineralogical information as well as to test the concept of automatic mineralogical analysis as a parameter for computer control of a mineral processing plant.

It appears possible to apply automation to the proposed image analysis system. First the system already operates automatically once the sample is inserted into the scanning electron microscope. The problem that remains is collecting the sample from the plant, polishing it, and inserting it into the scanning electron microscope. Collecting the sample can be readily achieved with a sampling thief in the same way that samples are taken for on-stream XRF analysis. The sample can be automatically dried and mixed with epoxy to embed the particles. CSIRO in Australia have already built a polishing unit that is virtually automatic. It can polish the section in minutes and

transfer it from one place to another. It seems that mounting the sample automatically in the scanning electron microscope can also be achieved.

All this might seem a bit far out, but only 20 months ago I speculated at a meeting at CANMET on the concept of the image analysis system that I described. I learned shortly afterwards that CSIRO already had a prototype in operation and one year ago IRSD in Paris had installed a similar system. We expect to have one in our laboratory by February, 1984.

The object of automated mineralogy in a mineral processing plant is to increase metal recoveries which in turn will increase ore reserve potential of the country and increase profits of operating companies.

9. THE NEED FOR NEW TECHNOLOGY

V.J. Jutronich, Corporate Manager,
Uranium Projects,
Denison Mines

I'm from a very aggressive mining company and it is even successful in the current economic situation. We've had two gentlemen speak today about competition from Japan and I think it is something that we have to look at because there are other countries also appearing on the horizon. One I can think of is Korea, and I think China is not far behind. In addition to that, our research in the past has always made sure that we've kept ahead of the rest of the world, but we have two other sleeping giants. I think India will be one and Africa will be another one.

The pendulum with us has swung to the right and I think it is getting to the stage where these countries are going to catch up to us. Some of them have mining as their only industry - and they're going to learn from a lot of the things that we are doing. I would like to point out that I am very pleased to be at this meeting today. To me it is showing a new change in the strategy that we have in Canada and in the North American continent.

After listening to the people speaking today I still have one fear, and the fear is that we are not communicating enough with each other. I have looked at what Mr. Valeri spoke to us about and he has indicated to us that there is a potential and we have to look at it. We have to try and draw this potential in to the plans that we have. I look at CANMET and how they have tried to get going with the industry. I felt that I kept myself well acquainted with what is happening and today I learned one or two things. But I'd still like them to have a look at some other things: they could bring some of the experts which we have in private industry into this total scheme.

Thank you gentlemen.

10. ROBOTICS AND AUTOMATION IN PHYSICAL METALLURGY

Dr. W.N. Roberts,
Physical Metallurgy Research Laboratory
CANMET.

I will briefly discuss the opportunities and the problems of applying robotics/automation to four major areas of physical metallurgy: metal casting, metal forming, welding, and non-destructive evaluation.

Metal Casting

Die casting and permanent mould casting are well known for zinc, copper and aluminum alloys but the Physical Metallurgy Research Laboratory is extending techniques to at least iron casting and possibly steel casting. If successful, this new technology could create a new market for pick-and-place robots. In Japan, over 7000, and in Europe, about the same number, of this type of robot are used in the die casting and moulding industries. I will not dwell further on this subject because it has been amply covered by Mr. Valeri in his presentation.

Metal Forming

The Canadian steel industry is interested in automation of metallurgical proceses as a means of obtaining quality control, diversifying product lines and reducing cost. The lack of adequate sensing devices to monitor many processes or perhaps a lack of knowledge of the monitors available and their installation is seen as a major obstacle to computer control and ultimately to full automation. The Canadian Steel Industry Research Association (CSIRA), PMRL/CANMET and NSERC recently commissioned Mr. Eric Leaver, with a quarter century of experience running his own instrument company and experience in supplying instrumentation to the pulp and paper industry, to conduct a survey of sensor needs in the Canadian steel industry ([1]).

This was followed by a workshop held in Toronto in March 1983, to bring steel industry representatives and sensor suppliers together [2]. The workshop discussed in individual sessions the measurement of several key parameters, required before steel mill automation can be readily achieved:

1) Temperature
   -Sensors are not available for continuous monitoring of the temperature of the steel bath, or of the surface and internal temperature of ingots in soaking pits or in slabs in reheat furnaces.
   -Pyrometry as practised in Canadian mills rarely achieves its potential accuracy.

2) Geometry of Hot-Rolled Shapes
   -Present technology is adequate for dimensional measurement of hot-rolled shapes.

3) Geometry of Flat-Rolled Products
   -Available sensors for shape and profile control are not entirely satisfactory; fast response times and capacity to measure sheet thicknesses to high accuracy are required.

4) Internal Defects
   -Larger defects can be detected by methods such as ultrasonics but sensors are generally too unrefined to detect all significant defects and to measure their dimensions.

5) Surface Defects
   -Eddy current and ultrasonic methods do not yet have the resolution to count and categorize all significant defects.

6) Chemistry
   -Measurement of interstitials needs development. Canadian oxygen probes are inferior to European models. There is a need for on-line analyses of carbon, sulphur, and manganese.

It is my understanding that another workshop, bringing together researchers and users, is to be held in the near future, probably in the spring of 1984. People attending this seminar might well wish to attend this workshop for possible new opportunities for application of robotics/automation in the steel industry.

I must say that despite deficiencies in sensors, many Japanese mills have extensively automated their operations, to a much greater extent than any European or North American mill. For example, at the Kimitzu Works of Nippon Steel, virtually all operations in the heavy-plate mill, slabbing shop, hot-strip mill, cold strip mill, and section and rod mill are controlled by a hierarchy of four levels of computers. In Canada, Algoma, Stelco and Dofasco have introduced a large degree of automatic control in their newer hot-strip mills.

I should briefly mention our attempts at automating an experimental pilot-scale rolling mill at PMRL/CANMET (3). This mill is used to simulate industrial rolling mill schedules and is a unique facility in Canada and, perhaps, in North America. Industry finds it very attractive to use it for developing new rolling schedules because tests on a full-scale mill involving a single heat of steel could cost as much as $100,000.

The PMRL/CANMET mill is a two-high, single stand, reversing mill. At present a microcomputer is used to acquire, store, and display measurements of the following parameters:

1) Mill load from the average signal of two load cells mounted under rolling positioning screws in each side of the mill stand.

2) Temperature from a thermocouple imbedded in the specimen.

3) Roll gap from the potentiometer coupled to the rolling screwdown mechanism; the measurement is corrected for roll deflection.

4) Motor voltage and current, from which mill power can be calculated.

5) Roll speed which gives a measure of strain rate.

6) Pass start time

In the future, it is hoped to use the microcomputer on-line to predict the optimum mill setting for a given pass from calculation of data on previous passes to yield a product of required shape and mechanical properties with minimum power consumption.

Welding

In welding, we have seen the introduction of true robots, particularly in automobile production. A new Nissan Plant in Tennessee is to have 270 robots, about 60 for Metal Inert Gas (MIG) welding, 60 for resistance (spot) welding and the balance for assembly operations and spray painting (4). Hitachi and General Electric are major manufacturers of welding robots.

Until recently Japan and Europe have shown far more interest in industrial robots than North America. It has been predicted that it will be 1990 before the U.S. approaches Japan in numbers of advanced robots.

In large scale welding, the application of robots is not so evident. An experimental narrow gap welding system was recently installed in our laboratory. It is capable of welding very thick plate by either submerged arc, using a flux, or by MIG, using an inert gas as a shield against oxidization. The system is automated to the extent that it will make a single pass along the workpiece without further intervention by the operator but must be reset for the next pass. The Swedish firm, ESAB, manufactures enormous column and beam machines which will weld large objects such as pressure vessels. These machines will make repeated weld passes along a predetermined track without human intervention.

Non-Destructive Evaluation

In PMRL, a prototype of a portable x-ray stress diffractometer has been developed for determining stresses in structures under field conditions. I suspect it could well

benefit from robotics. At present the head of the instrument is mounted on a yoke with X, Y and Z motions, which will fit readily on linear structures such as transmission line pipe. If the head could be mounted on the arm of a robot, it could be positioned much more readily with respect to structures of complex shape.

Another application of robotics in non-destructive evaluation would be to position the bridge of an ultrasonic testing array with respect to a structure under examination.

I hope that these few examples of robotics/automation in physical metallurgy will suggest other potential applications in Canadian metallurgical industries.

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11. APPLYING ROBOTICS TO A BAR-AND-HAMMER TASK IN A COPPER SMELTER

Don Saville,
Superintendent of Industrial Engineering,
Milling, Smelting and Refining,
Ontario Division, INCO.

I think I am the only one here who has a contract to build something rather than to look at something. I would like to start by saying I was happy to hear that Bill Petruk and a couple of speakers have come up from underground. You people that are involved in mining think that mining stops once you get to the surface, but mining only begins there in a broad sense when we get into the metallurgical scene of extracting the values.

I was introduced as being involved in milling, smelting, and refining. In our case at INCO we have two ranges of products: nickel and copper. They don't come to us that way, despite what the miners do; they still come all bound up in a rock along with at least 27 other elements that we have to extract. Some of them are very hazardous to our health. Perhaps a major difference between manufacturing and mining is the productivity opportunities. In manufacturing, an automated robot is used to increase your manufacturing capabilities.

We don't have that opportunity in our particular mining business. I suppose if you had a gold mine this would not be true, but we don't have a gold mine, although gold is one of our by-products. We don't have the opportunity to lower our unit cost by making more nickel because we can't sell it although we are the largest nickel company in the world. The market is not there at this time and I don't see that it will be there for some time to come. The same thing is true of copper.

To get specifically to the project, André, out of a number of things that are possible to do in our industry in the surface plants that I am involved in, perhaps a thousand applications are there of various types of robotics. Through a series of sixteen processes and criteria we managed to arrive at what I judged

I was getting nudged for by Hank when we were sitting down there. He said, couldn't you find a better name for this project except a bar-and-hammer or a hammer-and-bar project? I can give that credit to CANMET who decided to name it. I had another name for it but they chose to ignore it.

But that is what it is. Believe me, in our industry and I think, in related metal industries and mining industries, the most common physical task is that of a bar and hammer.

One illustration I have of this is in one warehouse complex in our company... one out of maybe five major warehouses.

In the year 1980 we delivered to people ten thousand hammers of various sizes. There are only eleven thousand people who work there. I'm one of the guys who didn't get one, but the rest got one. It's a very common application. We sought to address that application with some degree of automation or perhaps robotics.

Looking at the bar-and-hammer applications around our company we narrowed them down to a specific one behind a converter where a man is required to push a bar through a tuyere with just a tight opening in the back of the converter into molten metal... molten - metal at a high temperature. Most of the time he is required to use a small hammer to assist him in getting the bar in and sometimes to assist him in getting it out. One of the reasons we chose that application was the environment itself. It was a poor place to start but we figured that if we were successful in this area then we could be successful anywhere, even underground. We have an area that is hot, dusty, gassy at times with various gases; it is also cold in the winter time; it has a very high noise level; the people working there are dressed like outer space people, they have to be protected in leather aprons, specially built gloves, special hearing devices to block up their ears, special helmets, and special goggles.

Despite that, and this is a point I have only heard very briefly addressed here this morning, when we finally arrived at this contract and made this known to the workers in this specific area they were not happy at all. I went myself to speak to these

people and say, we're going to try and develop a device that will replace you in this terrible job. They suddenly decided this was a very good job, it wasn't as bad as they used to think the week before or in the last three union contracts that had this on it. That is the major problem in getting into robotics in our industry and I am sure any industry. What are you going to do with the people that aren't working on those jobs any more?

DISCUSSION

12. OPEN DISCUSSIONS

André Potworowski
I would like now to open the discussion to the floor and I may take advantage as Chairman to ask the first question of each of the panelists. Given Vince Valeri's exposé of how far the manufacturing sector has gone and given Jay Pathak's vision of what the mine of tomorrow may look like, what do each of the panel members think is the most urgent priority that has to be addressed? Who would like to take it first David?

David Gladwin
For André's sake, very briefly, the most urgent development priority right now, as I see it is that somehow we have to achieve a greater balancing of the application of new technology across the different parts of the industry and the different components of a mine operation. It seems incredible to have a highly developed, sophisticated remote control mining machine dependent on manual scaling and rock bolting right in front of it.

Don Saville, INCO
I think David had that written down! I see some difficulties still in translating to our area the manufacturing capabilities of robots to pick and place or pick and weld in view of what, at present, we seem to require which are unique, one-tasked robots that are only required to do one thing and are perhaps only capable of doing one thing.

I foresee going further into our industry where we are looking at one specific task in one part of an operation which is very complex and very massive - involves six separate plants altogether. What we need is to take one of those plants and look at total automation which would involve some robots and some remote control manipulators. I would like to point out on behalf of CANMET and André and the people here that we at INCO would not be in this robot project without some CANMET support; not only some financial support but some CANMET technical support. Because like most of the mining industry, except for the uranium people, we are not very rich these days and probably wouldn't take the risk capital available to go into this thing totally on our own.

So the push has got us started with one robot and I am hoping that I will translate this into a plant and subsequently to whatever might be required.

Vic Jutronich, Denison Mines
Listening to some of the speakers today, some of them have a direct interest in what is happening and quite often the problem could revolve around their own situation. The other thing that you also have to look at is that we may be making our problems too complicated and we have to look at it from a simplified position.

If I look at mining, I think a lot that has been done at Westinghouse could be applied to underground. I have some ideas of how we could apply it at Elliot Lake today, and I will go back with those thoughts, to see if I can change some of the thoughts at the mine site. But it is the people themselves at the mine site that will have to start thinking in new ways, relating to this type of thing.

So, I think that we will all have to change. We may have to look at different functions within the underground mine itself, and then put the whole picture together.

Vince Valeri, Westinghouse/Unimation
I have been asked many many times, "Come into our factory and show me where to use these wonderful robots that I've heard about". Our approach is that we think you should forget about these things called robots. They are nothing more than a tool like any other tool and you should concentrate on your own objectives and on developing the processes that you need in order to attain those objectives and then see how you are going to get some manipulator to do that - it might be a robot, it might not.

I don't think these seminars really should be pointed towards robotics; I think they should be towards productivity and automation and a way of thinking to help you achieve the objectives you want. Jay said, the thing we need right now to implement his vision or concept of uranium mining is crushers. It may be a way of thinking that is not, how do I robotically

crush this material, but what is the process I use? Maybe you shouldn't think of even using the word "crushing" - use "rock disintegration", or something, so that you start to look at technical processes rather than mechanical processes, or oxygen lance cutting or something; not this simple little manipulator called a robot, but your process and your thinking as to how you are going to achieve those things. I would say, although I am in the robotics business, stop thinking robotics and start thinking automation and new processes.

Art Hunter, National Research Council

I've got a bit of background in robotics. I would like to first off just make a little statement before I lead to a question. My understanding of robotics is perhaps a little narrower than we've been talking about for most of the morning. The difference that I would like to address is the difference between mechanization and the capability of a robot to respond automatically to some non-linear situation that develops. Of course, when one looks at what a robot under that definition should be able to do, it means that one immediately turns to looking at the sensor development. I was very pleased to hear Dr. Roberts address the problem and, of course, Dave Gladwin and a couple of the other speakers have as well, but I would like to emphasize that, at least in my view, the sensor development is really the key to robotic development. All the mechanizations, the mechanical design, the electrical design, the control systems, etc., can be so designed to accommodate whatever sensors are available. I'm particularly interested in, of course, some of the comments of Dr. Roberts and the other speaker, Dr. Petruk, with regards to image analysis systems and the x-ray stress diffractometer, which I would put in the category of being very useful sensors as well, that are clearly applicable to robotics.

When one takes a look at the mining world and mineral processing world, clearly one is looking at the development of sensors which will function in an environment which is particularly nasty in that it is dirty and dusty - unfriendly is the term that was used as well, which I noted down, whether it be underground or on the surface. Of course there is a great deal to be done, as Hank has indicated, to go from the technology that was developed for the CANADARM to that which is used in this environment that is going to require extremely rugged designs.

What I would like to put to the panel is, what are the latest developments that are going on in sensory development, specifically rather than broad brush, and if there is not much going on addressing sensor ruggedization and design, what should be done to meet the needs of the mining communities?

André Potworwoski
I wonder it the people who are involved in the CONSPEC firm - would you like to answer that question? If you could take the microphone please, and introduce yourself because I think your development is particularly relevant.

L. McCullough, CONSPEC
Our main contribution, I guess, in this area is what we call Computer Integrated Mining - trying to integrate all the mining activities, primarily underground, into a total system. The particular question, of course, was sensors, and these are always very important in any system. We ourselves are not sensor manufacturers but we are constantly searching the world for sensors that will integrate with our systems. To a great extent the U.S. Bureau of Mines and CANMET both have been involved in a lot of these programs over the past years, as well as many of the various manufacturers, and there have been great strides in this area, but a lot of it has been related more to environmental sensing rather than to actual production equipment. Obviously, the government activities have been in environmental areas because this is really their mandate and, of course, where their dollars come from.

The mining industry, on the other hand, has a commitment to make money, which relates more to the productive nature of their business and there really has not been a lot of application from the various government bodies, in directing the research into this area - there is more and more today in that I think they are re-assessing their mandate; this is certainly true of the U.S. Bureau of Mines whom we interface with very closely, as well as at CANMET. So I think there are going to be a lot of new things to come out of it. I don't think it is the point to get into any specifics but I think this is the direction that we've seen things go. Sorry I have to leave.

André Potworowski
Thank you very very much. Is Louis Sirois or Daniel Laguitton still here? Would you like to tell us something about how you see the role of sensors in your area of simulating the whole milling process.

Daniel Laguitton, Mineral Sciences Laboratory
Well, I am not there yet. I think that the stage before developing sensors is the stage where you have to analyze the process and decide what sensors are required. That means process analysis and process theory and I know all my activities right now are analyzing mineral processing in order to develop control strategies. This would mean try to identify what would be the best variable to be measured, what would be the best location to measure it - and that is already something that takes lots of time - and the next stage, which can be developed in parallel also, but logically it should come afterwards, would be to develop the machine, the equipment, the sensor, if it's going to measure that. And then the next stage would be couple that sensor to what you may call a robot or an automatic control system where the process theory would be used in the sensor or would be used in the supervisor to optimize the process.

That's the way I see it in the near ages of robotics, and so I have every intention of remaining there because I think that it's required. We are not going to make outstanding advances in the process optimizations by just developing sensors if we don't understand the basic variables that are at play in the processes, so that we can develop the best sensors to measure them.

Don Saville, INCO
From my direct application point of view I would like to answer that question with some of the questions that were asked today, about machining and as Henk was alluding to, uptime of machinery and monitoring of machinery in order to keep it on strength.

There is a noise-sound integrator that has been developed, which costs twelve hundred dollars American. It learns by listening to the machine and it integrates both the frequency as well as the amplitude and remembers that pattern, and as your

machine operates, if that pattern goes out of sync or if that pattern is changed in either amplitude or frequency, you can in fact now program your, whatever it might be, to respond to those changes. It's a very simple method, and it's the method that we normally use in driving our automobiles or our--whatever it might be--to monitor the performance and that is listening to the noise of our equipment. It doesn't require any development and it's not something that is years away. It's something that has been developed several years past and we are not really using it in those areas.

I would comment certainly that the lack of sensors in the metallurgical end of mining is a great impediment to moving into total automation. I'm sorry to say that, certainly in Canada, and the rest of the world as far as I know, the pyrometallurgical business is still fifty percent black art. It is done by some person who in some manner looks at his particular metal and gives it some test that may or may not exist in fact and decides if it is a good one or a bad one.

We have no way of determining in a scientific manner, and therefore measurable with some instrumentation, the end point of a converter. There are a number of ways that it is done that I've been told about. None of them make any sense and some of them are contrary but they all seem to work. We have very little control over our roasting process. We don't really know what happens. All we know is that it comes out all right. In order to take people away from those work faces and eliminate those particular tasks in the industry, we have to find ways to measure whatever it is. Someone said earlier that we have to find out what it is that we need to measure and then find something to measure it.

Roy Hoffman, C.A.E. Electronics

I'd like to express my appreciation to the organizers of this seminar. I found it a very helpful one. We are a high technology company who are in the mode of looking around for applications of high technology in some of our traditional industries and are very interested in what is going on in this area. I appreciate the spirit of the discussions today in terms

of trying to listen to each other, because I think that is something that's very very important - that we listen carefully to each other and that we refrain from making broad sweeping statements (for example there was one suggestion that mining is in the neanderthal stages of development) those kinds of statements are not helpful. I appreciate the spirit of listening and co-operating and sharing ideas because that's one way we are going to be able to think broadly, as one person has suggested, to hear what other people are talking about, try and understand where they are at and I hope that's something that we can do.

One quick comment I would like to make about robotics was brought to me recently on a trip to Japan and that was to think of robotics by comparing them to a computer. If you think of it, a computer is basically capable of processing information and we know how profoundly the computer has changed society. But a computer is limited in terms of its capability to take action based on its information processing capability.

The essence of robotics from one point of view is, a computer and you add, shall we say, a manipulation capability to it, and you are able to not only process information but take action. I personally have found that a helpful way of looking at it.

I would like to ask one question regarding that of the people here. Dr. Pathak, briefly, at the end of his talk, alluded to the need for mine status information systems, and also earlier in the talk from Unimation there was mention that the real thrust in factory automation right now is in some sort of total computer-integrated manufacturing and our friends from CONSPEC have suggested that is their interest.

I am curious if anybody would like to respond. I guess that is on the applications side of the actual need for real time monitoring of everything that is going on in the mine and having total real time information collection display and analysis. Thank you.

Jay Pathak, Mining Research Laboratories, CANMET
I think I have indicated what MSI is. What I am trying to do or tell people is to progress slowly and solve the problems which are solvable now. And I think this is monitoring and control. Monitoring is easier than controlling because of the oscillations set off by changes in the ventilation circuits which are very difficult to define mathematically. Mine Status Indicator which I differentiated a little bit because that is both our information log system as well as on/off system which we can achieve probably tomorrow. But it doesn't exist. That is why I have given the progression of development towards the way we should go.

But ultimately, the total mine information system on line will come, if not today, tomorrow, and if we don't do it, probably it will be done by Mitsubishi, or somebody. So that is what my aim of telling you was - just start progressing right now and whatever is available, whatever we can do, start now. Monitoring and controlling are rather difficult so let's go for MSI and monitoring system, then go to control, then go to the total mine information system, which we can do.

Louis Cabri, CANMET
I am following up on something Don Saville said just now. There are many processes in the metallurgical and mining industries of which we don't understand the fundamentals. That is why it is hard to automate and find robotics applications, and I think this should be recognized. We should really consider that the aspects of the mineral industries have not had the same sort of fundamental research as other hard sciences and this is brought out by the comments of Don Saville.

David Gladwin, Research Program Office, CANMET
Basically, the capability exists today to monitor some basic functions in the mines, which can contribute dramatically to the overall operation, and in fact can be tied into a control system.

I think it is essential that once we have a monitoring capability of any sort we try to build into that automatic application of the monitoring information to control systems.

For example, we can today monitor electrical draw at various points in the mine, we can monitor compressed air draws at various points, the pump activities and what not. Just as easily as we can monitor those, we should be able to control them, and I think there are examples in place, what we might call in robotics, rudimentary systems. But there are systems established which monitor, interact, check against parameters, and control. I believe that those systems have a lot higher degree of acceptance at the operation than a mere monitoring system. But they are still not really well enough developed to be fully useful... to have full control. This has been alluded to a number of times. However, just standing back and observing this over the past several years, with the advent of the computer and recognizing what can be computed, in a very short time we moved further than in the past fifty years. Therefore, I can see very shortly that we will have the sensors required, we will know the various fluctuations that are possible, and the only thing that will prevent it will be economics to bring this in.

H. Van Deudekom, Vadeko International
I'd like to respond to Dr. Cabri. In a sense what you are saying is that the metallurgical processes are not adequately characterized at the moment to allow us to even specify what kind of sensors we need and how to control them, so in a sense that also is an implication as to what the priorities should be as far as reasonable development expenditures.

I think the second aspect, is monitoring. We can see monitoring, at least from my perspective, in a sort of an evolutionary sense. You start off initially by using monitoring to determine what the health of the system is. You might want to use it for off line full diagnosis. You might want to use it to collect information and then subsequently analyze it to determine what the status is, what the condition is of the machine, and when, at what stage eventually it may break down and, therefore, determine when maintenance is required. As you gain greater understanding of the process, and this really is a situation where you need masses and masses of information to just understand one machine, I think then you get to the stage where you can use real time techniques in order to make corrections -

if you like, use it in a control sense - so that not only can you monitor the information but you also use the information to, in a real time sense, control the process.

Vic Jutronich, Denison Mines
I would just like to highlight one comment on MSI that was brought up by Dr. Pathak, and also what Henk is saying right now. When you looked at the table of MSI, those were only some of the controls that we have to go through in the mining industry to keep a plant operating properly. A lot of that information only comes in two weeks, three weeks, a month behind time, and by then it is too late to do anything. If you have a look at what Dr. Pathak said, if you can put in a monitoring system that can tell you at the end of the shift exactly what has happened you can take action right at that time. If you have a look at what Henk is saying, at the end of a shift, you can have a look at something that comes off the machine, you can tell about the condition of the machine, and these are the things where we'll see a great improvement in productivity.

John Wilson, Ontario Centre for Research Machinery
I would like to thank the organizers for inviting me to this event. I found it most stimulating and interesting and I think that some of the other gentlemen who have come up to the mike, and also some of the panelists have said that this little seminar is going to lead to other seminars. Basically I am not going to talk very long. This is usually not my way of doing things!

I would like to say this, and that is look, we have the technology, we can monitor systems underground, we can monitor the height of the muck in the ore passage, we can monitor ventilation conditions, we can raise and lower ventilation doors. Look, we have the technology, let's put it to work. That's all. Thank you.

Don Saville, INCO
I'm glad to hear you say that. I hear you talking about automated mills and we have had an automated mill for the last fifteen years - thirty thousand tons - the only reason we have people in that mill is to track material that comes up from the

mines. That's true. We have eight people a shift who sit there and do nothing but take all this junk out of the ore; otherwise we would have two people in the control room watching a computer run this mill. The technology is there.

Some things need to be done in the other parts of the industry. Wherever we have wet processes, that is some liquid in contact with some form of the ore, we have automatic sampling, automatic assaying, automatic collection of that data, translation of it, and so what! We already have too much data. I'm not sure that we need so much real time data acquisition, we don't know what to do with what we have now and if we learn ten times as much we'll probably do nothing whatsoever. Now we do this time and time again. We, in effect go up higher in the building so we can see further and now we can see 'way out there' but we still don't know what to do with the information we receive. Real time data acquisition I hear being talked about down here. We had bids from five different companies five years ago to do that to our smelter. We didn't do it - we couldn't afford it, but it was there then, I presume. They sounded convincing. If we'd had the money we would have done it. But the technology is mostly there. There's some that is missing perhaps in the molten metal end of it where were not quite sure what is going on in that bubbling cauldron of whatever, and we're not quite sure when to stop making it.

Neil Roberts, PMRL, CANMET
Don has given me an "in" here. The primary problem identified in this survey of sensors and a subsequent workshop was simply the measurement of temperature on a continuous basis in a molten bath of metal and, you know, you can put in numerous thermocouples and have them chewed up by the mill, time and again, or you can use pyrometry which doesn't seem to be very accurate. At present there doesn't seem to be a very good method--cheap and reliable--for measuring temperature. They identified many other problems as well but that was, almost, the primary one.

Daniel Laguitton, CANMET
In the previous remark, we have a mill that is automatic. If it were not for transporting material from the mine there would be nobody required in the mill. My question is, can it be shown

that that mill makes the best use of energy provided in the grinding circuit? Is the process optimized, or which way are we going to optimize that mill once we have made it a gigantic robot that takes material from the mine and produces a concentrate? Is it at a static point where we have built a robot? What do we do with it? We have to go back to the basics and try to redesign all the sensors in that mill because, by knowing the process better we find out that that robot has been built on a state-of-the-art knowledge of mineral processing which can be improved. So we should not fall in the trap of making it automatic for the sake of making it automatic because the purpose of the mill is to make profit, which means to concentrate the minerals in the most efficient way, which brings me back to what I said before. I don't want to repeat it.

André Potworowski
I guess Daniel's call of going back to basics is, I think, a thoroughly good recommendation for CANMET as a whole, and a good point on which to close the discussion. Thank you all.

CONCLUSION

13. CONCLUDING REMARKS

Dr. W.G. Jeffery,
Director-General,
CANMET.

Ladies and Gentlemen, it has been a most interesting morning. Before I make a couple of comments on the proceedings I would like to make sure that I don't forget, first of all, to thank Paul Mainwaring for running this show. He has taken on the chore of organizing the seminar series within the Division of Mineral Sciences and, as Dr. Whitham described in his opening remarks today, this particular meeting has blossomed to something which we did not anticipate when we started.

But that is fine. We were very willing to adapt, and I think it has been a most interesting morning. I would like to thank André Potworowski too, for giving the support of his Office of Technology Transfer within CANMET and, in particular, I would like to thank those speakers who came from industry to make their presentations this morning - Vince Valeri, Henk Van Deudekom, Vic Jutronich, and Don Saville, as well as my colleagues from CANMET.

It really has been an exploratory session in many ways for CANMET. It started out as one of a series of seminars, designed to highlight aspects of robotics development and remote manipulative techniques so that our scientists would have a heightened awareness of applications in relation to their own detailed research programs. That was fundamentally the objective. In the presentation by Dave Gladwin we have tried to indicate to our visitors some of our general trends and directions in this field, which no doubt will be modified over time, and the way we've chosen in applying leverage of whatever money and resources we have to stimulate this area. We think that it is part of the mission of CANMET to do that.

Many things came through this morning which really are very interesting. Some of the philosophy of application is interesting. We all, I think, in this room, already knew that the robot is in an unfriendly environment when you take it

underground. There may be more applicability of robots to those repetitive, programmable types of applications in the mill, perhaps in the foundry, and some of the work related to physical metallurgy, but when you get into the mining environment that is a tough spot to put one of today's robots. Nonetheless, even if this is the case, I don't think it's our place in the Canadian mining industry to draw back from that and not look at the future: in other words to say, robots are useful in the manufacturing area, but not within the mining purview. If we do that, then we will lose out as a major world mining industry that should be at the forefront of new developments which we are trying to encourage in this country.

The philosophy, the very interesting statement by Vince Valeri of Unimation, that we should not think about robots, that we should think about automation and productivity and drive towards those goals, and look at what machinery is available to apply, is a most interesting comment.

On the other hand I think that we have to be aware of what the robotics industry and the remote control industry is producing in the way of equipment; because if we are a true R & D organization in CANMET and if our scientists and research engineers are functioning properly, there comes a point, and it has been alluded to this morning, where we may say there is a piece of equipment which will achieve certain things. To use it in mining, maybe we should go back to basics and change the operating parameters, maybe the mining process, the mining technology, so that it suits this piece of equipment which is on the shelf or virtually on the shelf. We mustn't, as an R & D organization in CANMET close the doors to enlarged thinking, and that is really what I hope that our scientists will gain from this seminar.

In terms of the CANMET mission and the allocation of scarce resources to this field, we seek input, we seek guidance from the industry. We serve the mining, the metallurgical, the mineral processing, and indeed the energy industries, and we may proceed with other seminars of this nature, perhaps more detailed, on some of the work we are trying to do. We look to those contract

proposals flowing in - we don't say we are going to be able to accept all of them - but participation between CANMET and industry will move technology forward in our field of interest.

So, in terms of our mission, both with respect to health and safety and productivity, this field of robotics and remote control serves all of these objectives. Sometimes I think CANMET is like that demonstration in the film this morning, where that robot was trying to find its way and probing out to all those barriers in order to get to its target. In terms of our R&D mission of trying to promote this technology, we need those signals coming in, from interested companies and the private sector who are involved in this area.

That is all that I wish to say and I will close this morning's seminar repeating my real thanks to those who came and contributed and to all who attended. Thank you very much indeed.

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